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AMERICAN SOCIETY OF CIVIL ENGINEERS

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TRANSACTIONS

Paper No. 1150

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

By Charles W. Raymond, M. Am. Soc. C. E.*

Some time before the appointment of the Board of Engineers which supervised the designing and construction of the New York Tunnel Extension of the Pennsylvania Railroad, the late A. J. Cassatt, then President of the Company, said to the writer that for many years he had been unable to reconcile himself to the idea that a railroad system like the Pennsylvania should be prevented from entering the most important and populous city in the country by a river less than one mile wide. The result of this thought was the tunnel extension project now nearly completed; but it is only in recent years that new conditions have rendered such a solution of the problem practicable as well as desirable.

Previously a tunnel designed for steam railroad traffic, to enter New York City near Christopher Street, was partly constructed, but the work was abandoned for financial reasons. Then plans for a great suspension bridge, to enable all the railroads reaching the west shore of the North River to enter the city at the foot of 23d Street, were

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carefully worked out by the North River Bridge Company. The Pennsylvania Railroad Company gave this project its support by agreeing to pay its *pro rata* share for the use of the bridge; but the other railroads declined to participate, and the execution of this plan was not undertaken.

New operating conditions, resulting from the application of electric traction to the movement of heavy railroad trains, which had been used initially in tunnels by the Baltimore and Ohio Railroad and was subsequently studied and adopted by railroads in Europe, made it possible to avoid the difficulty of ventilation connected with steam traction in tunnels, and permitted the use of grades practically prohibitive with the steam locomotive. The practicability of the tunnel extension project finally adopted was thus assured.

The acquisition of the control of the Long Island Railroad by the Pennsylvania Railroad Company, which occurred in 1900, introduced new and important elements into the transportation problem, from a freight as well as a passenger standpoint. Previously, the plans considered had for their only object the establishment of a convenient terminus in New York, to avoid the delays and difficulties involved in the necessity of transporting passengers and freight across the North River. When the Long Island Railroad became practically a part of the Pennsylvania System, it was possible and desirable to extend the project so as to provide, not only for a great prospective local traffic from all parts of Long Island, but also for through passenger and freight traffic to the New England States, and to and from all points on the Pennsylvania System, thus avoiding the long ferriage from Jersey City around the harbor to the Harlem River.

This paper has for its subject the New York Tunnel Extension project, and is intended merely as an introduction to the detailed accounts of the construction of the various divisions of the line to be given in succeeding papers prepared by the engineers who actively carried out the work. The project, however, forms the most important part of the comprehensive scheme adopted by the Pennsylvania Railroad Company for conducting its traffic into and through New York City, and a brief description of this general plan is therefore necessary in order that the relations of the tunnel line to the other parts of the transportation project may be clearly understood.

General Plan for Traffic Facilities at New York.

The component elements of the general plan outlined by the late A. J. Cassatt, President, in his open letter to the Board of Rapid Transit Railroad Commissioners of the City of New York, dated January 18th, 1906, are indicated on Fig. 1, and may be briefly summarized as follows:

1.—The Pennsylvania Tunnel and Terminal Railroad, generally referred to as the New York Tunnel Extension of the Pennsylvania Railroad. This line begins near Newark, N. J., crosses the Hackensack Meadows, and passes through Bergen Hill and under the North River, the Borough of Manhattan, and the East River to the large terminal yard, known as Sunnyside Yard, in Long Island City, Borough of Queens, New York. The line will be more fully described elsewhere.

2.—The electrification of the Long Island Railroad within the city limits.

3.—The Pennsylvania freight terminal yard and piers at Greenville, N. J., connecting by ferry with the Bay Ridge terminal of the Long Island Railroad.

4.—The Bay Ridge Improvement of the Long Island Railroad from East New York to Bay Ridge.

5.—Yards for increasing the freight facilities in the Boroughs of Brooklyn and Queens.

6.—The Atlantic Avenue Improvement in Brooklyn, involving the removal of the steam railroad surface tracks and the extensive improvement of the passenger and freight station at Flatbush Avenue.

7.—The New York Connecting Railroad, extending through a part of the Borough of Queens and crossing the East River by a bridge at Ward's and Randall's Islands to Port Morris, N. Y.

8.—The Glendale Cut-Off of the Long Island Railroad.

9.—New piers and docks in Newtown Creek at its confluence with the East River.

10.—Electrification of the United Railroads of New Jersey Division from Newark to Jersey City.

The parts sustained by these elements in the work of transportation and distribution are briefly as follows:

The New York Tunnel Extension is essentially a passenger line, although the Company has not only the legal powers but also the

facilities for making it a through route for freight if desired. It will transport passengers to and from the centrally located station at 33d Street and Seventh Avenue in New York City, joining the Long Island System at Sunnyside Yard, and, by means of the New York Connecting Railroad, it will form a link in the through traffic line, connecting the whole Pennsylvania System with the New England States. This line has been designed for the safe and expeditious handling of a large volume of traffic. The requirements include handling the heaviest through express trains south and west from the main line as well as the frequent and lighter local-service trains. For through service the locomotive principle of operation has been adhered to, that is, electric locomotives will take up the work of the steam locomotives at the interchange yard at Harrison, N. J., and, for excursion and suburban service to nearby towns, provision will be made for electric locomotives, or by operation of special self-propelled motor cars in trains, the project being planned to give the greatest flexibility in method of operation to meet the growing demand in the best way.

The New York Connecting Railroad has important functions both for freight and passenger service. When constructed it will be about 12 miles long, and will form a part of the line to the New England States for through passenger and freight service, and also carry local freight to and from Sunnyside Yard and Brooklyn, and all points on Long Island. By means of this line it will be possible to make the Brooklyn station at Flatbush Avenue a station on the through System for New England as well as the Western States.

The initial equipment of the Western Division of the Long Island Railroad for electric traction has been made in advance of the opening of the tunnel line in order to take care of the requirements of the Atlantic Avenue improvement. This improvement involved the elimination of grade crossings within the City of Brooklyn and the conversion of the railroad line which was previously on the surface of the streets to part subway and part elevated line from the Flatbush Avenue Terminal to East New York Station, a distance of 5¼ miles. One of the requirements of this improvement was that the motive power should be changed to some form of power not involving combustion. This led to the adoption of electricity, and, in order to meet operating necessities, involved the electrification of connecting lines beyond the improvement proper, so that local service could be handled to the end of the

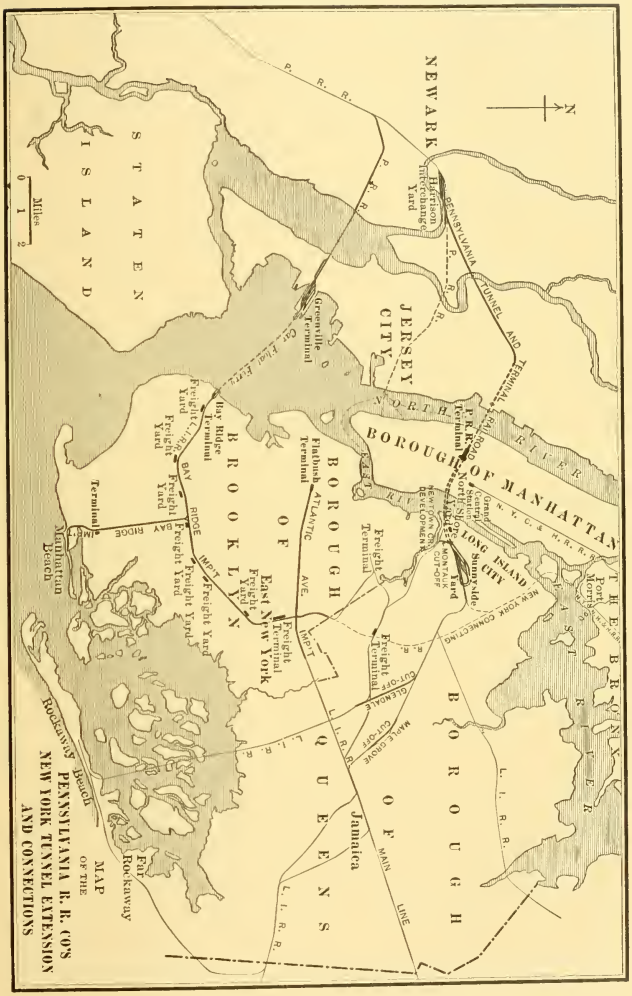

NEWARK
STATEN ISLAND
JERSEY CITY
BOROUGH OF MANHATTAN
BROOKLYN
BOROUGH OF QUEENS
BOROUGH OF THE BRONX
LONG ISLAND CITY
Harrison Interchange Yard
Greenville Terminal
Bay Ridge Terminal
Flatbush Terminal
East New York
Jamaica
Manhattan Beach
Rockaway Beach
Far Rockaway
Port Morris
Sunnyside Yard
Grand Central Station
North Shore Yard
Freight Yard
Freight Terminal
Miles
0 1 2
N
P. R. R.
L. I. R. R.
N. Y. C. & H. R. R. R.
PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD
NORTH RIVER
EAST RIVER
ATLANTIC AVE. IMPT.
BAY RIDGE IMPT.
NEW YORK CONNECTING R. R.
GLENDALE CUT-OFF
MAPLE GROVE CUT-OFF
MAIN LINE
MAP OF THE PENNSYLVANIA R. R. CO'S NEW YORK TUNNEL EXTENSION AND CONNECTIONS

FIG. 1.

runs without changing the motive power. The extent of the electrification thus required was found to be about 100 single-track miles. This extensive electrification work was undertaken and completed in the summer of 1905, upon the completion of the Atlantic Avenue improvement proper, and since that time has been in successful operation. On the near approach of the construction of the New York Terminal improvement, plans for additional electrification on the Long Island Railroad were made, and the work is now in progress on the extensive additions required to couple up the tunnel extension with the various lines centering at the Long Island City terminus.

The Bay Ridge Improvement of the Long Island Railroad comprises the readjustment of the right of way and the establishment of new grades in order to do away with grade crossings from the freight terminal at Bay Ridge to a junction with the New York Connecting Railroad at East New York, a distance of 10.4 miles. It also provides for the re-location of the line and the elimination of grade crossings on the branch running to Manhattan Beach, a distance of 3.7 miles. The work is being executed without interrupting traffic, and in all about 75 grade crossings will be abolished. This improvement became necessary in order to provide for the rapid extension of population into the suburban districts and for the present and future requirements of the section, to establish municipal conveniences and facilities, and to open additional streets across the right of way. To accomplish these ends, the line has been built in cuts and on embankments, there being about 6.4 miles of the former, 3.3 miles of the latter, and a tunnel, 3 500 ft. long, where the line crosses the Atlantic Avenue improvement.

The Atlantic Avenue improvement, as mentioned above, involved the removal of the railroad tracks from the street surface for a distance of about 5¼ miles. This was done by constructing a series of elevated and subway structures, there being about 2.1 miles of the former, 2.4 miles of the latter, and 0.8 mile of approaches, eliminating more than 90 grade crossings. In the light of recent developments, it may be of interest to note that one of the reasons for establishing a combination elevated and subway line was that, at the time the improvement was projected, no underground railroad in the country, of similar length and carrying a heavy volume of local traffic, was operated by electricity, and public sentiment was against the operation of the entire length of

the line underground by steam power. This improvement also provided for depressing the entire Flatbush Avenue station and a freight yard. As the work progressed, the original plans for the station were greatly enlarged, the remodeled station covering about 61 city lots.

The main point of passenger distribution is the New York station. Other important stations will be Flatbush Avenue, Brooklyn; Jamaica, Long Island, where the changes to and from electric motive power will be made; and Newark, N. J. Many other places, including the seaside resorts on Long Island and in New Jersey, will feel the benefits of the direct tunnel railroad into and through New York City. The Glendale Cut-Off will materially shorten the route and running time from New York through the tunnels to Rockaway Beach.

The plans contemplate that passengers to and from the lower part of Manhattan will be carried by the steam line between Newark and Jersey City and cross the North River by ferry or the Cortlandt Street tunnels of the Hudson Company. Eventually, the old main line will be electrified and supersede the steam service between Newark and Jersey City.

The Greenville Yard is the most important point for the receipt, transmission, and distribution of freight. From this point freight can be transported, without breaking bulk, by a comparatively short car-ferry to the Long Island Railroad terminus at Bay Ridge, and thus a very large part of the Pennsylvania Railroad Company's floatage in New York Harbor and the East River will be abolished, the floatage distance being reduced in the case of the New England freight from about 12 to 3 miles. This traffic will be routed from Bay Ridge *via* the Long Island Railroad to a connection with and thence over the New York Connecting Railroad to the New York, New Haven and Hartford Railroad at Port Morris, N. Y.

As the facilities for the handling of freight in the Boroughs of Brooklyn and Queens had become insufficient for taking care of the prospective traffic, eleven new local delivery yards, having a combined area of about 2 153 city lots, have been established, and three existing yards are to be improved and enlarged so as to give a combined area of about 687 city lots. Of these new yards, the Bay Ridge freight terminal, containing about 790 city lots, is the largest; its functions have been described above. There is a freight terminal at East New York 200 ft. wide and a mile long, containing about 566 city lots,

which will be the distributing point of freight for the entire East New York section. This yard is depressed, and will be crossed by six viaducts carrying city streets. The North Shore freight yard, containing 109 city lots, is connected with the Montauk Division by an overhead construction, known as the Montauk Freight Cut-Off, whereby all freight traffic to Jamaica may be kept out of the way of the Jamaica passenger traffic from the tunnels.

It may be of interest to indicate briefly how much has already been accomplished in the execution of this general plan, and what still remains to be done for its completion.

The larger part of the electrification of the Long Island Railroad and the elimination of grade crossings within the built-up city limits, the Atlantic Avenue improvement, and the yard and piers at Greenville, have been completed. The Sunnyside Yard and the Glendale Cut-Off will be completed during the next twelve months. On the Tunnel and Terminal Railroad the embankment and bridge work across the Hackensack Meadows and all the tunnels and excavation from the west side of Bergen Hill to Long Island City, except a short section near the eastern end of the line, have been completed. The New York station and other buildings and facilities connected therewith are well advanced. The laying of the track, the electrification of the line, and the installation of the signaling and lighting systems are under way. It is anticipated that the line will be ready for operation in the spring of 1910.

Report has been made to the Public Service Commission that a large part of the right of way for the New York Connecting Railroad has been obtained, and more than $3 000 000 has been spent by this railroad. The piers and docks at Newtown Creek and the electrification of the line from Newark to Jersey City are not yet actively under way.

Estimated Cost of the Improvements.

As appears from the foregoing statement, only parts of the improvements contemplated in the general scheme have been completed, others are in progress, and others have not yet been commenced. It is therefore impossible at the present time to make a close estimate of the total expenditure involved in the execution of the entire scheme. The following estimate of the cost of the Pennsylvania Railroad Company's

improvements in the New York District when fully completed is based on the best information now available:

New York Tunnel Extension and Station, including Interchange Yards at Harrison, N. J., and Sunnyside, L. I., P. T. & T. R. R. Co.	$100 000 000
Long Island Railroad electrification, Bay Ridge and Atlantic Avenue improvements, Glendale Cut-Off, freight yards, and new equipment	35 000 000
New York Connecting Railroad, to be built jointly by the Pennsylvania R. R. Co. and the New York, New Haven and Hartford R. R. Co., about	14 000 000
Pennsylvania Railroad improvements in the State of New Jersey, electrification of line from Jersey City to Park Place, Newark, Greenville freight line and terminal on New York Bay	10 000 000
Total	$159 000 000

Corporate Organization and Franchise Conditions.

As the tunnel extension lies partly in the State of New Jersey and partly in the State of New York, it was necessary to charter two companies, each covering the territory within the State to which it belonged. The New Jersey corporation was entitled the Pennsylvania, New Jersey and New York Railroad Company, and the New York corporation, the Pennsylvania, New York and Long Island Railroad Company. These organizations were completed early in 1902. Subsequently, after the tunnels had been joined under the North River, the companies were consolidated, on June 26th, 1907, and thereby formed the present company under the name of the Pennsylvania Tunnel and Terminal Railroad Company, a corporation of both States.

Mr. Cassatt, President of the Pennsylvania, New York and Long Island Railroad Company, made application in its behalf for a franchise to extend the lines of the Pennsylvania Railroad by tunnels under the North River to a passenger station to be erected in New

York City and thence under the East River to a connection with the Long Island Railroad, on May 5th, 1902.

The franchise for that part of the tunnel line which is within the State of New York, that is, from the boundary line between New York and New Jersey, in the Hudson River, to the eastern terminus at Sunnyside Yard, Long Island, is contained in the certificate issued by the Board of Rapid Transit Railroad Commissioners of the City of New York on October 9th, 1902.

The essential features of the franchise have been summarized substantially as follows in the report of the Committee of the Board of Rapid Transit Railroad Commissioners of the City of New York, dated June 14th, 1902:

First.—A grant by the city in perpetuity of rights, subject, however, to a periodic readjustment of payments at intervals of twenty-five years, as follows:

(*a*) To construct and operate a railroad of two tracks from the boundary between New York and New Jersey under the Hudson River opposite the westerly foot of Thirty-first Street, Borough of Manhattan, thence running under the Hudson River and Thirty-first Street to the East River and under the East River to a terminus in Queens Borough. The Company is permitted on notice within ten years to give up the right to these two tracks.

(*b*) A like right for a railroad of two tracks beginning near the same point under the Hudson River, thence running under Thirty-second Street to the East River, and under that river to the terminus in Queens Borough, with a right for two additional tracks in Thirty-second Street, west of Ninth Avenue, and one additional track between Seventh and Fifth Avenues in Manhattan.

(*c*) A like right for a railroad of two tracks beginning at the station terminal site at Thirty-third Street and Seventh Avenue and thence running under Thirty-third Street and the East River to the terminal in Queens Borough, with a right for one additional track on Thirty-third Street, between Seventh and Fifth Avenues.

(*d*) A right to maintain a terminal station occupying the four blocks bounded by Thirty-first Street, Seventh Avenue, Thirty-third Street and Ninth Avenue, the lots on the east side of Seventh Avenue between Thirty-first and Thirty-third Streets, and the underground portions of Thirty-first and Thirty-third Streets, between Seventh and Eighth Avenues and between

Eighth and Ninth Avenues, the Company having itself acquired the land included in such four blocks and lots on the east side of Seventh Avenue.

(*e*) To occupy for such terminal facilities all of Thirty-second Street lying between the westerly side of Seventh Avenue and the easterly side of Eighth Avenue, and between the westerly side of Eighth Avenue and the easterly side of Ninth Avenue. As soon as the statutory right of the city authorities to make the conveyance shall be put beyond doubt the Railroad Company is obliged to buy such two portions of Thirty-second Street, which will then become completely dedicated to the purposes of their station. (These portions of Thirty-second Street were subsequently purchased by the Railroad Company.)

(*f*) To have along such routes the necessary facilities for the operation of passenger and freight trains, including telegraph wires and the various wires and cables for the distribution of power, heat, and light.

Second.—The requirement of the consent of the Mayor, the Board of Aldermen, the Board of Estimate and Apportionment, and the other authorities of the city having control of the streets.

Third.—The obligation of the Pennsylvania Company to begin construction within three months after obtaining the necessary consents and complete the railroad within five years after construction shall begin, except the route under Thirty-first Street, for the completion of which the company is allowed ten years after the completion of the remainder of the railroad.

Fourth.—Payments by the Pennsylvania Company for the first twenty-five years, as follows: A rental of $200 per annum for the right to occupy land under the Hudson and East Rivers outside of pier lines. A rental for ground within pier lines and for underground portions of streets in Manhattan Borough, at fifty cents per linear foot of single track per annum, for the first ten years, and during the next fifteen years one dollar per annum per linear foot. A rental for ground within pier lines and for underground portions of streets in Queens Borough at one-half the rates payable for Manhattan Borough. A rental for underground portions of Thirty-first and Thirty-third Streets, between Seventh and Eighth Avenues, and between Eighth and Ninth Avenues (such portions extending almost up to the surface, except under the south sidewalk of Thirty-first Street and north sidewalk of Thirty-third Street) at $14 000 per annum for the first ten years, and at $28 000 per annum for the next fifteen years.

For the portions of Thirty-second Street, between Seventh and Eighth Avenues, and between Eighth and Ninth Avenues, when the statutory power of the city to make a sale shall be put beyond doubt,

the city is to sell and the Railroad Company is required to buy such portions for the sum of $788 600. The rentals for river and track rights begin at the date of operation. For the underground spaces under Thirty-first and Thirty-third Streets, used for station extension, the rentals begin at the commencement of construction, or when the company entered thereon.

Such annual payments may be summarized as follows:

	First 10 years.	Next 15 years.
For river rights	$200.00	$200.00
For tunnel rights in Manhattan Borough, being 44 341 ft. (partly estimated) of single track	22 170.00	44 341.00
For tunnel rights in Queens Borough, being 8 100 ft. (partly estimated) of single track	2 025.00	4 050.00
For street rights on Thirty-first and Thirty-third Streets, north and south of terminal	14 000.00	28 000.00
In all, per annum	$38 395.00	$76 591.00

If the route under Thirty-first Street be availed of, these amounts will be increased by $16 652.50 for the first ten years, and by $33 305 for the next fifteen years.

The amounts to be paid are to be readjusted at the end of twenty-five years; and thereafter at intervals of twenty-five years. If the city and the Railroad Company shall not agree upon the readjusted rates, they are to be determined by the Supreme Court of this State.

Fifth.—The railroad to be entirely in tunnel except where it approaches the surface at its eastern terminal near Thomson Avenue, in Queens Borough. The uppermost part of the tunnel is to be at least nineteen feet below the surface of the street; but this limitation does not apply to the portions of Thirty-first and Thirty-third Streets opposite the terminal station between Seventh and Ninth Avenues, where the Company may occupy the underground portions of the street under the roadway to within thirty inches of the surface, and under the sidewalks on Thirty-first and Thirty-third Streets opposite to the station to within five feet of the surface, the company to properly care for sewers, water, gas and other pipes and underground structures lawfully in the street.

Sixth.—The company to make good all damage done to property of the city by its construction work or operations, and to abutting owners all damage done through any fault or negligence of the company, or of any contractor or sub-contractor engaged upon its work of construction or operation. The Tunnel Company to keep Thirty-first and Thirty-third Streets opposite the station well paved with smooth pavement and in thoroughly good condition.

Seventh.—Tunnel excavations to be done without disturbing the surface of the street, except in the portions of Thirty-first and Thirty-third Streets, and Seventh, Eighth and Ninth Avenues in front of the terminal station, and except in Queens Borough, with the power to the Rapid Transit Board, wherever conditions elsewhere make surface excavation necessary for efficient construction, to grant the right for such excavation, subject to conditions to be then prescribed by the Board. The tracks are to be constructed of the most approved plan so as to avoid noise or tremor. All plans for, and the method of doing, the work are made subject to the approval of the Rapid Transit Board.

Eighth.—The motive power to be electricity, or such other power not involving combustion as may be approved by the Board.

Ninth.—The company to have no power to carry on merely local traffic, except with the approval of the Board and for additional consideration to be paid the city. Traffic is defined as local which begins and ends in the city within five miles of the terminal station on Seventh and Ninth Avenues.

Tenth.—The railroad to be diligently and skillfully operated, with due regard to the convenience of the traveling public.

Eleventh.—The city to have a lien upon the franchise and real property of the company to secure the payment of rental.

Twelfth.—The rights of the city to be enforceable by action for specific performance, or mandamus, or otherwise.

Thirteenth.—The company not to oppose the construction of any rapid transit railroad along or across the same routes which do not actually interfere with the authorized structures of the company.

Fourteenth.—The city to have an ample right of inspection of the railroad, and to enter upon it for examination, supervision, or care of city property, or for other purposes.

Fifteenth.—The company to be bound to maintain and strengthen all parts of its railways under streets or avenues so that the same shall support safely any structures superimposed or which may hereafter be superimposed thereon by the city or under public authority.

Sixteenth.—The company to have the right to convey or mortgage the franchise, but every grantee, whether directly or under a mortgage, to assume the obligations already assumed by the Railroad Company and the Railroad Company not to be relieved of such obligations by the grant.

This franchise was passed by the Board of Aldermen on December 16th and approved by the Mayor on December 23d, 1902.

Subsequently, an agreement, dated June 21st, 1907, was entered into by the City of New York, the Tunnel Company, and the Long Island Railroad Company covering the construction of the Sunnyside Yard, which forms the eastern terminus of the line.

In pursuance of this agreement, the map or plan of the City of New York was changed by discontinuing or closing portions of fifty streets or avenues, and by changing the grades of sixteen streets or avenues, in the Borough of Queens, and the portions of streets and avenues thus discontinued and closed, most of which were not opened for public use, were sold to the Railroad Companies. The agreement, however, reserved to the City permanent and perpetual underground rights and easements to maintain in a reasonable manner, not inconsistent with the construction and operation of the railroad facilities of the Companies, its existing sewers, drains, and other sub-surface structures in, under, and through the lands within the lines of the discontinued portions of each of such streets and avenues, including the right to repair, rebuild, and enlarge the same, and to construct in a reasonable manner, not inconsistent with the construction and operation of the railroad facilities of the Companies, such additional sewers or drains in, under, or through the lands as may be hereafter required by the City, together with the right to enter upon the premises from time to time as may be necessary for the purpose of inspecting, repairing, constructing, or rebuilding the sub-surface structures.

The agreement required the Companies to construct at their expense, four viaducts or bridges over their tracks and terminal development, three with roadways 42 ft. wide, one with a roadway 60 ft. wide, and each to have two sidewalks 10 ft. wide, the work to include the paving of the roadways and sidewalks.

The Companies are further required to pay one-half the cost of the construction of the foundations, abutments, piers, superstructures, and approach of an additional viaduct or bridge over the Sunnyside Yard, to have a roadway not more than 60 ft. wide and two sidewalks each 10 ft. wide, and to grant the City of New York a perpetual easement for the continuance of the same in the location upon which it shall be constructed.

The agreement further provides that the Companies shall not injure the sewers or other substructures now existing or hereafter constructed under the streets and avenues, and, in case of injury, that they shall repair them or pay the cost thereof; that the viaducts shall be completed within the shortest time consistent with their safe and proper construction, and that during their construction temporary streets shall be provided for the accommodation of traffic.

The Companies are required to bear all the expense of changes of grade in the streets and avenues, except those made necessary by the construction of the viaduct or bridge to be paid for in part by the City; to indemnify the City against all liability for any and all damages which may accrue on account of any street which may be closed or the grades of which may be changed in pursuance of the agreement; to assume all liabilities by reason of the construction or operation of the railroads, or the construction of the viaducts, and to save the city harmless from any liability whatever, to either persons or property, by reason of the construction or operation of the railroads or the construction of the viaducts.

The Companies are also required to indemnify the City against and pay the cost of all alterations which may be required to the sewerage or drainage system or to any sub-surface structures and pipes laid in the streets or avenues on account of the construction and operation of the terminal, passenger yard, or freight yard of the Companies, or on account of the changes in grades or street system.

The Companies are authorized, if they deem it necessary to the construction or to the efficient operation of the terminal passenger yard or freight yard, to depress, at their expense, any pipes or other sub-surface structures now under the surface of any of the portions of the streets or avenues discontinued or closed, or to elevate and carry the same upon any of the viaducts or bridges, the plans of such depression or elevation to be approved by the Board of Estimate and Apportionment.

All works within, upon, or over the public streets and avenues are subject to the supervision and inspection of the proper municipal officer or officers, under such regulations as he or they may determine and be authorized by law to impose; and the plans for the construction of viaducts or bridges are to be approved by the Board of Estimate and Apportionment.

The Companies are required to cede to the City of New York perpetual easements for the right to continue and maintain the viaducts or bridges over the streets and avenues, sufficient for their control by the City for the purpose of police regulation and other control contemplated by the City ordinances for the case of streets or highways; reserving, however, the right to construct and maintain, at their own expense, such connections between the viaducts or bridges and their

property as shall not interfere with the use of the viaducts or bridges for street purposes.

The Companies are also required to cede to the City, grade and curb, portions of five existing or proposed streets or avenues, and to pave portions of two other avenues.

Mr. A. J. Cassatt, President of the Pennsylvania Railroad Company, was President of the Companies constituting the New York Tunnel Extension until his death on December 28th, 1906, and Mr. James McCrea, President of the Pennsylvania Railroad Company, was elected his successor, and is now President of the Pennsylvania Tunnel and Terminal Railroad Company.

Mr. Samuel Rea, Second Vice-President of the Pennsylvania Railroad Company, has served as Vice-President since the incorporation of the enterprise.

Mr. A. J. County has been Assistant to the President since June 26th, 1907, and prior thereto and from the incorporation of the tunnel enterprise served as Secretary of the Pennsylvania, New Jersey and New York Railroad Company and as Assistant Secretary of the Pennsylvania, New York and Long Island Railroad Company, which, as heretofore stated, constitute the Pennsylvania Tunnel and Terminal Railroad Company.

Engineering Organization.

Mr. Rea, Vice-President, has general charge of all matters involved in the designing and execution of the project.

The Board of Engineers.—Before the beginning of the work, the Management appointed a Board of Engineers which was instructed to examine into the New York Tunnel Extension project; to pass upon the practicability of the undertaking; to determine upon the best plans for carrying it out; to make a careful estimate of its cost; and, if the work was undertaken, to exercise general supervision over its construction.

President Cassatt's letter appointing the Board contains the following further instructions:

"You are requested to procure all additional information that may be needed, sparing neither time nor any necessary expense in doing so, for I am sure it is not necessary for me to say that, in view of the magnitude and great cost of the proposed construction, and of the

novel engineering questions involved, your studies should be thorough and exhaustive, and should be based upon absolute knowledge of the conditions."

The Board was organized on January 11th, 1902, when it held its first session, and continued in the performance of its duties until April 30th, 1909, when it was dissolved, its work having been completed.

The Board held regular and special sessions to receive progress reports from the Chief Engineers in direct charge of construction, and to consider questions relating to the plans and details of the work submitted by its members or referred to it by the Management. It then reported its conclusions to the Vice-President for approval before the work was undertaken.

The Management earnestly impressed upon the Board throughout the whole period of its labors, that the Tunnel Extension and facilities were to be designed and constructed without regarding cost as a governing factor, the main considerations being safety, durability, and proper accommodation of the traffic. No expenditure tending to insure these conditions was to be avoided.

The Board, when organized, was composed as follows: Col. Charles W. Raymond, Corps of Engineers, U. S. Army, Chairman; Messrs. Gustav Lindenthal, Charles M. Jacobs, Alfred Noble, and William H. Brown.

Mr. George Gibbs was appointed a member of the Board on April 9th, 1902. Mr. Lindenthal resigned on December 15th, 1903, and Mr. Brown resigned on March 1st, 1906. Mr. Rea and all the members of the Board are members of the American Society of Civil Engineers, and Mr. Noble is a Past-President of the Society.

Mr. William R. Mead, of the firm of McKim, Mead, and White, Architects for the Terminal Station, was associated with the Board for the consideration of architectural subjects.

Mr. Robert H. Groff, Secretary of the Company, was also Secretary of the Board until his resignation on January 31st, 1907. Mr. William Couper was Acting-Secretary from April 15th, 1907, to April 30th, 1909.

S. Johannesson, Assoc. M. Am. Soc. C. E., was Engineer Assistant to the Chairman from December 1st, 1905, to April 30th, 1909.

Division of the Work.—For the purposes of actual construction, the line was divided into four parts: the Meadows Division, the North

River Division, the Terminal Station, and the East River Division. A chief engineer appointed by the Management had charge of the construction of each Division. The chief engineers exercised full authority in the organization of the working forces, and in the general conduct and management of the work of construction on their respective Divisions, in accordance with the plans for such work approved by the Board of Engineers and the Management.

Architects were employed to design the Terminal Station building and superintend its erection; and structural engineers to design and erect steel structures and facilities, and carry on the work under the direction of a Chief Engineer of the Company.

Committees, consisting principally of officers of the Pennsylvania Railroad Company, co-operating with the regular engineering organization, were appointed to consider the operating features of the project, so that the experience of the Pennsylvania Railroad Company's organization might be utilized in the work.

Description of the Line.

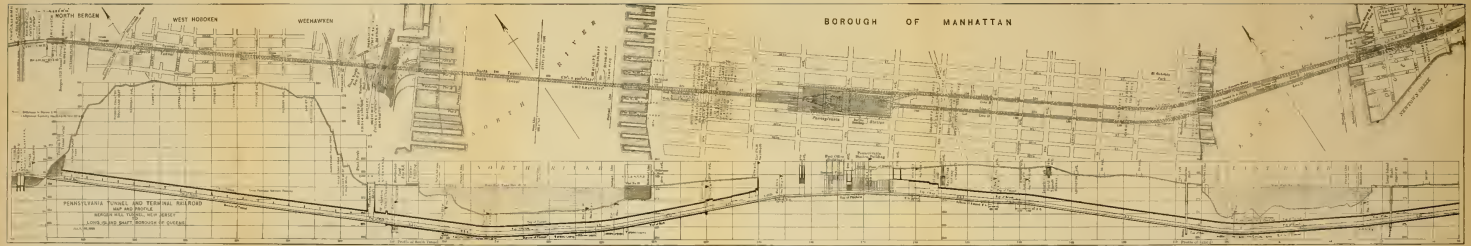
The following summary description of the various divisions of the line is intended to give a comprehensive idea of the general features of the project. Full details will be given in succeeding papers. The line and its respective divisions are shown on Plate I.

Meadows Division.—Chief Engineer until March 1st, 1906, Mr. William H. Brown, Chief Engineer, Pennsylvania Railroad Company, when he retired from active service with the latter Company; since March 1st, 1906, Mr. Alexander C. Shand, Chief Engineer, Pennsylvania Railroad Company.

This Division consists of an "interchange yard" at Harrison, near Newark, N. J., adjoining the tracks of the present New York Division of the Pennsylvania Railroad, and a double-track railroad across the Hackensack Meadows to the west side of Bergen Hill, a distance of 6.04 miles. The construction is embankment and bridge work, including bridges across the Pennsylvania, Erie, and Lackawanna Railroads, and the Hackensack River.

North River Division.—Chief Engineer, Mr. Charles M. Jacobs.

This Division commences at the west side of Bergen Hill and passes through the hill in two single-track rock tunnels to a large permanent shaft at Weehawken, near the west shore of the North River.


NORTH BERGEN
WEST NEW YORK
WEEHAWKEN
BOROUGH OF MANHATTAN
NORTH RIVER
EAST RIVER
PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD
MAP AND PROFILE
HUDSON AND MANHATTAN TUNNELS
LOOP, OLIVER AND 7TH AVENUE LINES
MANHATTAN TRANSFER STATION
HUDSON TERMINAL
PENNSYLVANIA TERMINAL
PENNSYLVANIA STATION
PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD
MAP AND PROFILE
HUDSON AND MANHATTAN TUNNELS, NEW JERSEY
LOOP, OLIVER AND 7TH AVENUE LINES
MANHATTAN TRANSFER STATION
HUDSON TERMINAL
PENNSYLVANIA TERMINAL
PENNSYLVANIA STATION
NORTH RIVER TUNNELS
EAST RIVER TUNNELS
HUDSON TERMINAL
PENNSYLVANIA TERMINAL
PENNSYLVANIA STATION
NORTH RIVER TUNNELS
EAST RIVER TUNNELS

and thence eastward a distance of 224 ft. to the Weehawken shield-chamber. It then passes under the river through two cast-iron, concrete-lined, single-track tunnels, with outside diameters of 23 ft., to a point under 32d Street, near Eleventh Avenue, in New York City, and thence through two single-track tunnels of varying cross-section, partly constructed in cut-and-cover, to the east side of Tenth Avenue. It then passes into the Station Yard and terminates at the east building line of Ninth Avenue. The work included the Station Yard excavation and walls from Tenth Avenue to Ninth Avenue, and the retaining walls and temporary underpinning of Ninth Avenue. The aggregate length of the line in this Division is 2.76 miles.

New York Station and Approaches.—Mr. George Gibbs, Chief Engineer of Electric Traction and Station Construction.

The Station and its approaches extend from the east line of Tenth Avenue eastward to points in 32d Street and 33d Street, respectively, 292 ft. and 502 ft. east of the west line of Seventh Avenue. This Division included the construction of subways and bridges for the support of 31st and 33d Streets and Seventh, Eighth, and Ninth Avenues, the Station building between Seventh and Eighth Avenues, the foundations for the post office to be erected west of Eighth Avenue, the service power-house in 31st Street between Seventh and Eighth Avenues, the power-house in Long Island City, the traction system, tracks, signals, and miscellaneous facilities required in the physical construction of the entire terminal railroad ready for operation. Messrs. McKim, Mead, and White were the architects for the Station and Messrs. Westinghouse, Church, Kerr and Company executed the structural engineering work, both in the station and for the support of the streets, as well as the construction of the subways.

The station is of steel skeleton construction with masonry curtain walls, all supported by a system of columns extending to a rock foundation. This building covers two city blocks and one intersecting street, and has an area of about 8 acres. It is 774 ft. long, 433 ft. wide, with an average height above the street of 69 ft., and a maximum of 153 ft. The main waiting-room is 277 ft. long, 103 ft. wide and 150 ft. high. The Concourse is 340 ft. long and 210 ft. wide.

The level of the track system below the street surface varies from 39 to 58 ft., and is from 7 to 10 ft. below mean high water in the harbor, thereby necessitating the establishment of an elaborate system

of drainage over the entire station yard area. Access to the street is gained by elevators and stairways.

To accelerate the loading and unloading of the trains, high platforms will be constructed in the station on a level with the floors of the cars, in order to avoid the use of car steps and increase the traffic capacity of the station.

There will be 21 standing-tracks at the station, and 11 passenger platforms, providing 21 500 ft. of platform adjacent to passenger trains. Within the station area, which from Tenth Avenue to the normal tunnel sections east of Seventh Avenue comprises 28 acres, there will be a total of about 16 miles of track.

The service plant for the installation of machinery for lighting, heating, and ventilating the station, and for operating the interlocking system, is located in an independent building south of the station.

The Power-House to supply the electrical energy for the operation of the tunnel line and the Long Island Railroad is situated on property in Queens Borough adjoining the present Long Island Railroad Station near the East River, and was constructed under the Chief Engineer of Electric Traction and Station Construction. As at present designed, the dimensions of the structure are 200 ft. by 262 ft., outside measurement. It can accommodate six generating units of 5 500 kw., the standard adopted for future work, and two of 2 500 kw. for lighting the tunnels. The ultimate capacity of this station when extended will be about 105 000 kw.

East River Division.—Chief Engineer, Mr. Alfred Noble.

This Division begins at the eastern limits of the New York Station at a point in 32d Street, 292 ft. east of the west line of Seventh Avenue, and at a point in 33d Street, 502 ft. east of the west line of Seventh Avenue, and also includes the excavation work and retaining walls for the station site and yard, to the track level, westward to Ninth Avenue. It extends eastward from the station under 32d and 33d Streets through tunnels partly three-track and partly so-called twin tunnels to Second Avenue; thence the line curves to the left under private property to permanent shafts a few feet east of First Avenue. Four single-track, cast-iron, concrete-lined tunnels, with outside diameters of 23 ft., pass under the East River, and, after passing through permanent shafts near the bulkhead line, reach the surface in Long Island City from 3 000 to 4 200 ft. east of the East River. The tunnel portals are in

PLATE II.
TRANS. AM. SOC. CIV. ENGRS.
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RAYMOND ON
PENNSYLVANIA RAILROAD: NEW YORK TUNNELS.

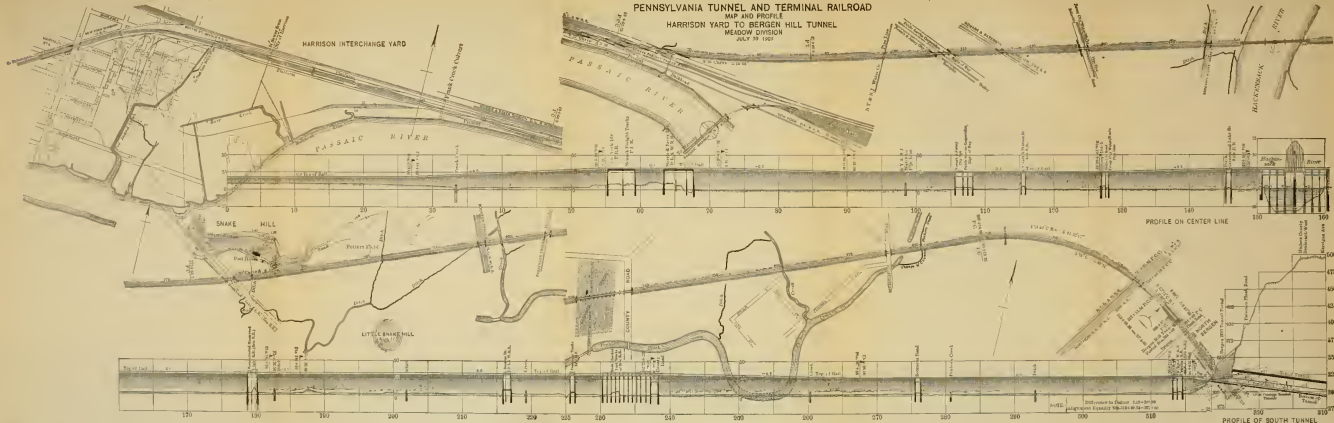
PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD

MAP AND PROFILE

HARRISON YARD TO BERGEN HILL TUNNEL

MEADOW DIVISION

JULY 10 1907



Sunnyside Yard, which extends to Woodside, the easterly end of the Division, and the Yard grading with its buildings and a number of City viaducts crossing it were executed under this Division. The total length of the Division is 4.48 miles.

The total length of the entire line is 13.66 miles. There are 6.78 miles of single-track tube tunnels, and the average length of the tunnels between portals is 5.56 miles.

General Considerations.

Details have been omitted from the foregoing description, as they can be treated better and more fully by the constructing engineers in succeeding papers. There are, however, some general considerations involved in the designing of the work, which may, perhaps, be referred to more conveniently in this introductory paper, and these will now receive attention.

In all parts of the work problems were encountered requiring for their solution large expenditures and much engineering skill; but many of these difficulties had been frequently met in previous engineering experience, and the methods of overcoming them were well understood. Thus, in the Meadows Division, a long and heavy embankment, part of which was on submerged meadow land, and many bridge foundations had to be constructed; in the Bergen Hill tunnels, very tough trap rock was encountered; in the tunnels under the city, the work was much complicated and its cost increased greatly by the necessity of caring for sewers, water and gas pipes, and the foundations of adjacent buildings; and many troublesome problems were met in the construction of the tunnels connecting the East River tunnels with the Sunnyside Yard.

The novel features of the project, however, were the great tunnels extending the line under the North and East Rivers. Tunnels of the kind contemplated, to be used for heavy and rapid railroad traffic, had never been constructed through materials similar to those forming the beds of the North and East Rivers. Questions arising in connection with the design and method of construction of the tunnels will be considered later. Here they are referred to only in their relation to the location and grades of the line, in which connection the conditions controlling their establishment were the most important elements.

Location and Grades.—It was desirable to make the tunnels between

the bulkhead lines of the rivers as straight as possible, and it was necessary to place them at sufficient depth below the dredging plane of the War Department (which in the North and East Rivers is 40 and 26 ft. below mean low water, respectively) to insure them against possible injury from heavy anchors or sunken vessels. Furthermore, they had to pass under the piers and bulkheads of Manhattan at a depth sufficient to make it certain that they would not affect the stability of those structures. Another consideration influencing the establishment of the depth of the tunnels below the bottoms of the rivers became important as soon as the method of construction by shields with compressed air was adopted, namely, the necessity of providing sufficient cover to guard, as far as possible, against blow-outs during construction.

The tunnels under the city, connecting the sub-river tunnels with the Terminal Station, were located so as to give as favorable grades as possible. The provision of the franchise requiring the tops of the tunnels to be at least 19 ft. below the street surface, which had been suggested by the Company to permit of future subways, had no effect on their location, as other conditions required them to be at a greater depth.

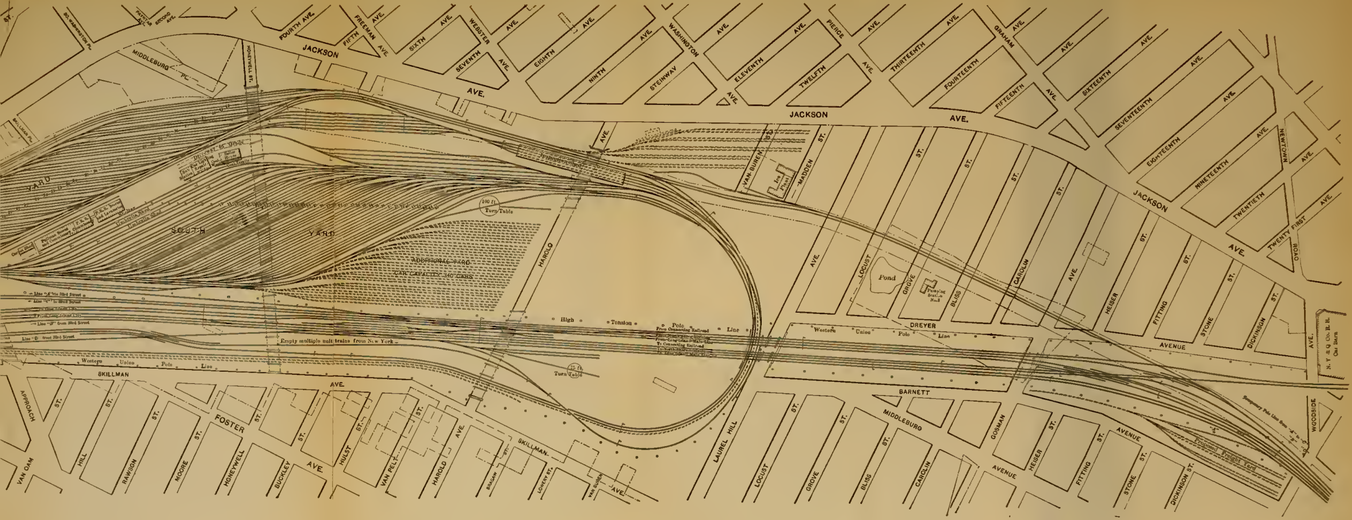
The line extending westward from Bergen Hill had to be established so as to give ample head-room at the numerous bridges over the railroads and highways which it crosses.

Eastward from the East River tunnels, the grades were established so as to rise as uniformly as possible to the level of the Sunnyside Yard.

The general features of the line, as finally adopted and constructed, are as follows:

The maximum grade west of the Terminal Station occurs on the New York side of the North River, and is 2% in the west-bound and 1.93% in the east-bound tunnels. The ruling grades (for the ascending traffic) being 1.32% in the west-bound and 1.93% in the east-bound tunnels. In the tunnels east of the Terminal Station the ruling grade is 1.5% for both east-bound and west-bound traffic. There is, however, descending with the traffic, a short section on a grade of 1.9 per cent. These grades would be objectionable with steam locomotives under a heavy traffic, but the development of the electric locomotive has rendered possible the operation of grades which would have formerly been considered prohibitive.

P. T. & T. R. R.
EAST RIVER DIVISION
SUNNYSIDE YARD
EAST RIVER
NORTH SHORE YARD
TENTH
NINTH
EIGHTH
SEVENTH
SIXTH
FIFTH
FOURTH
THIRD
WEST
VERNON
BORDEN
JACKSON
EAST
HUNTERS POINT
VAN ALST
ARCH ST.
BEECK ST.
CRANE
DAVIS
PEARSON
ANABLE
COURT ST.
THOMSON
NOTT AVE.
HUNTERS
HARRIS ST.
PURVES ST.
DUTCH KILLS ST.
QUEENS ST.
ORCHARD ST.
BARN ST.
BRIDGE
HENRY ST.
PROSPECT ST.
RADDE AVE.
QUEENSBORO BRIDGE APPROACH
ACADEMY
ELY
NOTT
TWELFTH
ELEVENTH
MEADOW
CREEK
DUTCH KILLS PL.
QUEENS PL.
ORTON
MANLEY
MOUNT
SCHOOL ST.
APPROACH
VAN DAM
HAYWARD ST.
DAVIS ST.
PEARSON
ANABLE
FLUSHING
FRONT ST.
Power Station
Platform


JACKSON AVE.
JACKSON AVE.
JACKSON AVE.
MIDDLEBURG PL.
HONEYWELL ST.
FOURTH AVE.
FIFTH AVE.
FREEMAN AVE.
SIXTH AVE.
SEVENTH AVE.
WEBSTER AVE.
EIGHTH AVE.
NINTH AVE.
WASHINGTON AVE.
STEINWAY AVE.
ELEVENTH AVE.
TWELFTH AVE.
PIERCE AVE.
THIRTEENTH AVE.
FOURTEENTH AVE.
GRAHAM AVE.
FIFTEENTH AVE.
SIXTEENTH AVE.
SEVENTEENTH AVE.
EIGHTEENTH AVE.
NINETEENTH AVE.
TWENTIETH AVE.
TWENTY FIRST AVE.
NEWTOWN ROAD
VAN BUREN ST.
MADDEN ST.
YARD
SOUTH YARD
100 ft. Turn Table
ADDITIONAL YARD
CAR CAPACITY 340 CARS
HAROLD AVE.
High Tension Pole Line
Empty multiple unit trains from New York
Western Union Pole Line
SKILLMAN AVE.
75 ft. Turn Table
AVE.
LOCUST ST.
Pond
GROVE ST.
BLISS ST.
CAROLIN ST.
AVE.
HEISER ST.
FITTING ST.
STONE ST.
DICKINSON ST.
DREYER AVENUE
Western Union Pole Line
BARNETT AVE.
MIDDLEBURG AVENUE
N. Y. & Q. Co. R. R. Car Barn
WOODSIDE AVE.
Proposed Freight Yard
APPROACH
VAN DAM
HILL ST.
RAWSON ST.
MOORE ST.
FOSTER AVE.
HONEYWELL ST.
BUCKLEY ST.
HULST ST.
VAN PELT ST.
HAROLD AVE.
SKILLMAN AVE.
LAUREL HILL
LOCUST ST.
GROVE ST.
BLISS ST.
CAROLIN ST.
GOSMAN ST.
HEISER ST.
FITTING ST.
STONE ST.
DICKINSON ST.

From the junction with the Pennsylvania Railroad, near Harrison, N. J., to Woodside, Long Island, a distance of 13.66 miles, there is an average of 1.5 curves per mile; the line having a total curvature of 230 degrees. The maximum curvature is 2 degrees.

Method of Construction of Sub-River Tunnels.—The character of the material through which the tunnels were to be constructed differed greatly in the two rivers. The bed of the North River, at the level of the tunnels, consists of silt composed principally of clay, sand, and water, while that of the East River is formed of a great variety of materials, such as quicksand, sand, boulders, gravel, clay, and bed-rock. When the method of construction had to be decided there were no thoroughly satisfactory precedents to follow in the case of either river, although the Gas Tunnel under the East River, the partly constructed Hudson Tunnels under the North River, the St. Clair Tunnel under the St. Clair River, the Blackwall and several other tunnels under the Thames River at London, supplied much useful information. The smaller tunnels for a lighter traffic, since so successfully constructed under the North and East Rivers, had not then been completed. Under these circumstances, it was the desire of the Management that the Board should receive and consider proposed methods of construction from all available sources; and during the first year of its labors much of its time was devoted to the examination and discussion of projects submitted for its consideration by engineers and practical builders, some of these projects having decided merit. Most of the methods proposed involved temporary structures, or the use of floating plant, in the navigable channels of the river. This was objectionable in view of the resulting obstruction to the enormous river traffic. After full consideration of the subject, it was decided to adopt the shield method with compressed air for the construction of the tunnels under both rivers, this being the only method recommended by the Chief Engineers, and having the great advantage of conducting all operations below the bottom of the river, thus avoiding obstruction of the channel.

Experience has shown, as was anticipated, that it is much more difficult to construct tunnels in such material as occurs in the East River and on the New Jersey side of the North River, than in more homogeneous material such as is found in the greater part of the North River. During the progress of construction under the East River, there were frequent blow-outs through fissures opened in the

river-bed, and the bottom of the river over the tunnel had to be blanketed continuously with clay, to check the flow of the escaping air.

In view of the serious difficulties which it was thought might be encountered in the application of the shield method to the East River work, other methods for the execution of this part of the project received special consideration, one of the methods considered being the freezing process. It was proposed to drive a small pilot tunnel and freeze the ground for a sufficient distance around it by circulating brine through a system of pipes established in the tunnel. The pilot tunnel was then to be removed and the full-sized tunnel was to be excavated in the frozen material and its lining placed in position. By this means, it was intended to avoid the danger incident to the use of compressed air in material of greatly varying character. This method contained too many elements of uncertainty to justify its adoption; but as the Management considered it desirable to have, if possible, an alternative method, an extended experiment was made with the freezing process. A pilot tunnel, 7 ft. 6 in. in diameter, was driven in the bed of the East River for a distance of 160 ft., circulating pipes were established in it, and brine at a very low temperature was passed through the pipes until the ground was frozen for a distance of about 11.5 ft. around the tunnel. Observations to determine the rate of cooling and other important points connected with the process were carefully made. When it was found that the construction of the tunnels was progressing satisfactorily by the shield method, and that so much time was required to freeze the material that the freezing process could not be used to advantage in this particular case, the experiment was discontinued.

Design of the Sub-River Tunnels.—The sub-river tunnels consist of a circular cast-iron shell, of the segmental, bolted type, having an outside diameter of 23 ft., lined with concrete having a normal thickness of 2 ft. from the outside of the shell. Through each plate of the shell there is a small hole, closed with a screw plug, through which grout may be forced into the surrounding material. Each tunnel contains a single track. A concrete bench, the upper surface of which is 1 ft. below the axis of the tunnel, is placed on each side of the track, the distance between benches being 11 ft. 8 in. These benches contain ducts for carrying electric cables. The main reason for adopting single-track tunnels instead of a larger tunnel containing two tracks was to

avoid the danger of accidents due to the obstruction of both tracks by derailment or otherwise. The tunnels are made just large enough to allow the passage of a train with perfect safety, as it was believed that with such an arrangement thorough ventilation would be secured by the motion of the trains. Experience seems to justify this assumption, but, in order to assure thorough ventilation under unusual conditions, such as the stoppage of trains in the tunnels, a complete ventilating plant will be provided for each tunnel. The rapidity and safety of construction were increased by making the tunnel as small as possible, one of the difficulties in the shield method of construction being the difference in hydrostatic pressure between the top and bottom of the shield, which increases with the diameter of the tunnel.

The concrete lining was introduced to insure the permanency of the structure, strengthen it from outward pressure and guard it against injury from accidents which might occur in the tunnel. The side concrete benches were suggested by Mr. Cassatt, President, to confine the trains to the center of the tunnels in case of derailment, and to furnish sidewalks on each side of the trains so as to obviate the necessity of walking on the track.

Refuge niches are constructed in the side benches of the tunnels. Manholes, splicing chambers, pump chambers, and other features for the handling of the electric cables and drainage, are established at intervals.

At points where unusual stresses were anticipated, as for instance where the tunnels pass from rock to soft ground, the shell was composed of steel instead of cast-iron plates. In the North River tunnels the concrete lining in the invert and in the arch was reinforced by longitudinal steel bars, but these were not introduced in the East River tunnels.

Other details connected with the structures, including the drainage, lighting, ventilation, signaling, and electrification systems, will be given in succeeding papers.

Stability of the Sub-River Tunnels.—One of the most important questions connected with the design of these tunnels was their probable stability under the long-continued action of a heavy and rapid railroad traffic. The tunnels are lighter than the materials which they displace even when the weight of the heavy live load is included. In the East River the character of the material seemed to justify the conclusion

that the tunnels would not be displaced even under the action of the live load. In the North River, however, the tunnels are enveloped by a soft silt and it was at first apprehended that some system of supports would be advisable to carry the heavy traffic and insure the tunnels against displacement under its action. To meet this contingency, which was then believed to be a very serious one, it was proposed to sink cast-iron screw-piles through the bottom of each tunnel into and through the underlying silt until satisfactory bearing material was reached. The pile supports were worked out in sufficient detail to be embraced in the contract for the construction of these tunnels, with provision, however, for omitting them should it be determined subsequently that their use was undesirable. The contract plans contained provisions for sliding joints where the piles pass through the tunnel floor, so that the live load might be carried directly to the pile heads by a system of girders, and also for attaching the piles directly to the tunnel, the two plans being alternatives.

Investigations, made during the progress of the work to determine the physical character of the silt and its action on the tunnels, suggested the possibility that the use of pile supports might be inadvisable. This view was confirmed by actual experience in the operation of the tunnels of the Hudson Companies between Hoboken, N. J., and Morton Street, Manhattan, which were opened to traffic in February, 1908. The stability of these tunnels under traffic gave further assurance that supports were unnecessary under the North River tunnels of the Pennsylvania Railroad Company, and they were therefore dispensed with.

Cross-Passages Between the Tunnels.—The Bergen Hill tunnels, the land portions of the North River tunnels and the tunnels under Manhattan are connected by cross-passages at intervals varying from 50 to 300 ft. As it was the desire of the Management to provide every arrangement possible to insure the safety of its passengers and employees and also to provide for the convenience of inspection, the question of establishing cross-passages between the tunnels under the rivers was given most careful consideration. The conclusion was finally reached that such passages as it was possible to construct between these tunnels might increase instead of diminish the danger in case of accident. No more cross-passages have therefore been constructed in the sub-river sections, except in the East River, where there is a cross-

passage and pump chamber combined between each pair of tunnels about 750 ft. from the Manhattan bulkhead line.

Probable Results of the Improvements.

In preceding pages reference has been made to the general objects of the improvements included in the project of the Pennsylvania Railroad Company for the New York District. While it is impossible, in this introductory paper, to analyze fully the transportation problem at New York, it seems desirable to indicate briefly some of the more obvious effects which the improvements may be expected to produce upon the distribution and handling of traffic.

New York City owes its position as the business metropolis of the country mainly to its magnificent harbor and the extensive waterfronts on its deep, wide rivers, which furnish unrivaled facilities, at a short distance from the sea, for foreign and domestic water-borne commerce, its foreign commerce being about half the total for the whole country. The water-transportation facilities of the port and its tributaries, therefore, have always been guarded with jealous care, not only by the local commercial interests but also by the General Government.

During recent years, however, the population of the metropolitan district has increased so enormously that New York is now the greatest terminal passenger and freight traffic center in the country; and in manufactures it ranks first among American cities. The new commercial interests thus created are of at least equal importance with those of the water-borne commerce, although their existence and development are largely the result of the water facilities of the port.

The local passenger and freight traffic of the Pennsylvania and of other railroads reaching the west shore of the North River is conducted by car-floats and ferry-boats which deliver their loads at piers on the Manhattan waterfront and elsewhere in the harbor. These boats obstruct and endanger the free navigation of the channels and occupy space along the waterfront greatly needed for the accommodation of the long-distance water-borne commerce, especially on the North River.

In the East River the importance of ferry-boats as a means of traffic distribution has already been greatly reduced by the construction of bridges and tunnels which provide for the greater part of the passenger and vehicular traffic. The North River, however, by reason of its greater width and the comparative slowness of its currents, is by far

the more important waterway for the use of ocean-going vessels of the larger classes. In this river the conditions for the construction of bridges, within the limits of commercial convenience, seem to be practically prohibitory. Tunnels, for the transportation of passengers and the diversion of the freight traffic from the inner waters of the harbor, are apparently the only available means of relief.

When the new line is in operation, a very large part of the New York passenger traffic of the Pennsylvania Railroad will be carried to the New York Station at Seventh Avenue and 33d Street and the rest will go to Cortlandt Street through the Hudson Company's tunnels. Thus a large portion of the Pennsylvania passenger ferry traffic, which amounts to more than 91 000 passengers daily, will be practically eliminated from the water-transportation problem. In addition, a large part of the Long Island Railroad's passengers will use the station at Seventh Avenue and 33d Street, and its ferry traffic will be reduced accordingly.

The new arrangements for the transfer of freight from Greenville to Bay Ridge will relieve the inner waters of the harbor of a large volume of obstructive car-float traffic. There appears to be no reason why this traffic should not be eventually conducted through tunnels under the outer harbor, should future transportation conditions justify the enormous cost of such structures.

It is to be remarked that while these new arrangements greatly reduce the passenger and freight water transportation, they have no effect on the large vehicular traffic across the North River which must continue to be conducted by ferries until it can be otherwise provided for. As long as these conditions exist, ferry-boats must be used in large numbers and continue to obstruct the North River. This difficulty probably cannot be overcome by the construction of bridges, as in the case of the East River, but it does not seem too much to expect that, eventually, tunnels to provide for the vehicular traffic, like the Blackwall tunnel under the Thames, will be established under the North River.

It would be interesting to estimate the increase in railroad traffic capacity resulting from these improvements, but the data required for this purpose are not available. Some idea of the increase in passenger traffic capacity resulting from the establishment of the tunnel line may be obtained by comparing the proposed daily train-movements for

the new station with the train-movements at other important railroad stations. The daily train-movements of six such stations are given in the following table:

	Total trains in and out for 24 hours.	Movement at maximum hour.
Jersey City	281	29
Broad Street Station, Philadelphia.	538	48
Union Station, St. Louis	462	89
South Terminal Station, Boston	861	87
Grand Central Station, New York	357	44
*Pennsylvania Station, New York	500	50

The freight capacity of the Pennsylvania System at New York has been greatly enlarged by the construction of the Greenville Yard and the facilities connected therewith, but it is impossible to estimate the amount of this increase. However, it is worthy of remark that, during the period from 1900 to 1906, the freight traffic density on the directly-operated lines of the Pennsylvania Railroad Company increased from 3 268 330 to 4 742 081 ton-miles per mile of road, a growth of nearly 50 per cent. Doubtless the improved freight facilities of the New York District had a large influence in the development of this increase.

One of the most interesting points connected with this development of traffic facilities is its influence on the relative distribution of population in the different parts of the metropolitan district. In 1907 the population per acre of the different divisions of Greater New York was reported as follows: Manhattan, 157; Brooklyn, 29; Bronx, 14; Queens, 3; Richmond, 2. The effect of new lines connecting some of these districts, and sections of New Jersey not far from the North River, with the business center of the city will undoubtedly be to increase greatly their population-density. It does not seem probable that the population-density of Manhattan will be sensibly reduced by these improvements, for they stimulate the increase of population, and apparently no increase of transportation facilities can keep up with the growth of the city. The population of a great commercial city must be congested near the business center. This is a necessary condition of its existence. All that can be done to meet this condition is to

* Proposed train service when Station is opened, the ultimate capacity of the Station being in excess of 1 000 trains per day.

provide all possible facilities for moving the people into and out of the business districts and within its limits.

During recent years the business population of the lower part of the Borough of Manhattan has become greatly congested. Very high buildings, providing business accommodations for large numbers of people, have been constructed, and these people must move to and from their working places at about the same times, that is, at the "rush hours" in the morning and afternoon, at the beginning and ending of the working day. Every effort has been made to provide for this immense and rapidly increasing local passenger traffic, by the construction of surface, elevated, and subterranean railways; but the demand for transportation has increased much faster than the facilities can be provided, and it is evident that the limit of down-town passenger traffic facilities has been very nearly reached.

Apparently, the only remedy for these conditions is the movement of business and the people transacting it up-town or to the Boroughs of Brooklyn and Queens, which are now readily accessible by tunnels and subways. This movement, of course, is resisted by the great real estate and money interests centered in the lower part of the city, but, notwithstanding this resistance, the improvement has commenced and has rapidly advanced. The great retail houses are being established above 23d Street; the banks and brokers' offices are rapidly appearing around the new business center of the city. The facilities afforded by the telephone and the subway for communication with the money center have doubtless greatly promoted this up-town movement.

When the Pennsylvania Tunnel Extension is in operation, the easiest and quickest way for the passenger to reach the city from Newark will bring him into the Pennsylvania Station at Seventh Avenue and 33d Street. The schedule fast time from Newark to the New York Cortlandt Street Station is now 25 min. This may be reduced to about 18 min. by the use of the Hudson Company's tunnels, and while this involves inconvenience in changing transportation at Jersey City, yet it brings the traveler three blocks nearer Broadway. The time from Newark to the Pennsylvania Station will be about 17 min., and the trip will be made without change of transportation, so that, undoubtedly, by far the greater part of the Pennsylvania's passenger traffic desiring to reach the shopping and hotel center of the city will go to the new up-town station.

The effect of the Tunnel Extension in increasing the volume and rapidity of the up-town movement and the real estate values will be very great; indeed, its influence is already apparent, although the line is not yet opened for traffic. With the extension of the present subway down town on the west side with direct connections to Brooklyn, and up town from 42d Street to the Bronx, with connections to permit convenient transfers between these two straightaway subways—one on the east side and the other on the west side of Manhattan—the Pennsylvania Station will become a great center for receiving and distributing passenger traffic between all the Boroughs of the City and outlying points. The new post office to be established adjacent to the Terminal Station will also greatly assist in accelerating the up-town movement.

In concluding this account of the New York Tunnel Extension project, the writer desires to pay a tribute of admiration and respect to the memory of the late A. J. Cassatt, President of the Pennsylvania Railroad Company, to whom the conception, design, and execution of the project are mainly due. His education and experience as a civil engineer, his thorough knowledge of all the details of railroad construction, operation, and management, gained by long and varied service, the directness, clearness, and strength of his mind, and his great executive ability, placed him at the head of the railroad men of the country. In the consideration of great problems, whether of transportation, finance, commerce, or political economy, he was almost unequaled, owing to the breadth, originality, and decisiveness of his character; yet his manner to his subordinates was so direct and simple that he seemed unconscious of his own superiority. Great as it is, the New York plan of improvement is only one item in a far-reaching scheme of development which became the policy of the Pennsylvania Railroad Company through Mr. Cassatt's advice and influence, yet his strongest interest was doubtless centered in the New York works. It is the sincere regret of all connected with the design and execution of the project that he did not live to see its completion.

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TRANSACTIONS

Paper No. 1151

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

THE NORTH RIVER DIVISION.

By Charles M. Jacobs, M. Am. Soc. C. E.

These observations are written with the purpose of outlining briefly, as far as the writer was concerned, the evolution of the scheme of bringing the Pennsylvania Railroad and the Long Island Railroad into New York City, and also, as Chief Engineer of the North River Division of the New York Tunnel Extension of the Pennsylvania Railroad, to record in a general way some of the leading features of the work on this division, which is that portion of the work extending from the east line of Ninth Avenue, New York City, to the Hackensack Portal on the westerly side of the Palisades, as an introduction to the papers by the Chief Assistant Engineer and the Resident Engineers describing in detail the work as constructed.

It may be stated that, since shortly after the year 1871, when the Pennsylvania Railroad system was extended to New York Harbor through the lease of the New Jersey Lines, the officers of that company have been desirous of reaching New York City by direct rail connection.

The writer's first connection with the tunneling of the North River was early in 1890, when he was consulted by the late Austin Corbin, President of the Long Island Railroad Company and the Philadelphia

and Reading Railroad Company, as to the feasibility of connecting the Long Island Railroad with the Philadelphia and Reading Railroad (or with the Central Railroad of New Jersey, which was the New York connection of the Reading) by a tunnel from the foot of Atlantic Avenue, Brooklyn, under the Battery and New York City, and directly across the North River to the terminal of the Central Railroad of New Jersey. Surveys, borings, and thorough investigations were made, and the Metropolitan Underground Railroad Company was incorporated in the State of New York to construct this railroad. Mr. Corbin, however, was aware that, in the transportation problem he had in hand, the Central Railroad of New Jersey and the Philadelphia and Reading Railroad were not as important factors as the Pennsylvania Railroad, and, in consequence, he abandoned the scheme for a tunnel to the Central Railroad of New Jersey for a line direct to the Pennsylvania Railroad terminal in Jersey City.

Meantime, the Pennsylvania Railroad Company, as a result of its investigation of the matter, in June, 1891, thought that the most feasible project seemed to be to build tunnels for rapid transit passenger service from its Jersey City Station to the lower part of New York, connecting there with the rapid transit systems of that city, and also extending under New York on the line of Cortlandt Street, with stations and passenger lifts at the main streets and elevated railroads.

The late A. J. Cassatt, then a Director of the Pennsylvania Railroad Company, and previous thereto as General Manager and Vice-President (and later as President) of that company, was deeply interested in obtaining an entrance into New York City, but was not satisfied with the proposed rapid transit passenger tunnels which required the termination of the Pennsylvania Railroad trains at its Jersey City Station. Therefore, upon his request, in September of the same year, another study and report was made by Joseph T. Richards, M. Am. Soc. C. E., then Engineer of Maintenance of Way of the Pennsylvania Railroad, on a route beginning in New York City at 38th Street and Park Avenue on the high ground of Murray Hill, thence crossing the East River on a bridge, and passing around Brooklyn to Bay Ridge, thence under the Lower Bay or Narrows to Staten Island and across to the mainland, reaching the New York Division of the

Pennsylvania Railroad at some point between Rahway and Metuchen. Mr. Cassatt also had in mind at that time a connection with the New England Railroad, then independent, but now part of the New York, New Haven, and Hartford Railroad system, by means of the Long Island Railroad, and a tunnel under the East River, which in later years, as the result of further consideration of the situation, has been covered by the proposed New York Connecting Railroad with a bridge across the East River and over Ward's and Randall's Islands.

As a result of these investigations, the late George D. Roberts, who was then President of the Pennsylvania Railroad Company, authorized an expenditure of about $25 000 for soundings to determine the nature of the strata for tunneling under water. These soundings were carefully made by Mr. Richards with a diamond drill, bringing up the actual core of all rock found in crossing the waters of New York Bay from the west to the east side and extending from the Narrows to the Jersey City Station of the Pennsylvania Railroad.

After these investigations had been made, early in 1892, Mr. Roberts expressed himself as being favorable to the undertaking, with the definite limitation that the tunnels must be for small cars doing local suburban business, and for the transfer of Pennsylvania Railroad passengers to and from New York, Brooklyn, and Jersey City, and not in any way to be tunnels for standard steam equipment, the expense for terminals and the prohibited use of coal for fuel in such tunnels not warranting any broader consideration. Under such instructions, the interests of the Pennsylvania Railroad Company for effecting a physical entrance into New York City in that year were turned over to Samuel Rea, M. Am. Soc. C. E., then Assistant to the President of that Company, who has been identified with the investigations, and the progress and construction of this work since that time, Mr. Cassatt also working in conjunction with him on the plans then and since considered by the Pennsylvania Railroad Management.

On October 5th, 1892, Mr. Rea, under special direction of President Roberts, made an extended investigation of the various routes which had then been projected for extending the system into New York City by rail or transport, and reported to Mr. Roberts that, in his opinion, because of the limitation of the tunnel scheme to rapid transit trains and the consequent transfer of passengers and traffic carried in passenger trains, and because of the drawbacks caused by the use of steam

locomotives in full-sized tunnels, and the objection to cable traction or any system of transportation which had not then stood the test of years of practical service, the plan of the North River Bridge for reaching New York City and establishing a terminus therein was the best that had been evolved up to that time. The plan provided a direct rail entrance into New York City for all railroads reaching the west side of the Hudson River, and also for the New York Central and Hudson River Railroad, as well as adequate station facilities in that city. This bridge would have had one clear span of 3 100 ft. between pier heads, landing on the New York side at the foot of West 23d Street, and thence the line would have passed diagonally to the terminus at Sixth Avenue and 25th Street. The location of the terminus was subsequently changed to the vicinity of Seventh Avenue and 36th Street. The bridge was designed with three decks: The first or lower deck was to accommodate eight steam railroad tracks; the second was to have six tracks, four of which could be assigned for rapid transit trains operating with electric power, and the other two for steam railroad trains; the third deck, reached by elevators, was to be a promenade extending from anchorage to anchorage. A connection with the Eleventh Avenue tracks of the New York Central and Hudson River Railroad was to bring the trains of that road into the Union Station. The Bridge Company had a Federal charter—granted in 1888—with broad powers. Gustav Lindenthal, M. Am. Soc. C. E., was Chief Engineer, and he and Mr. Rea were corporators and among its early promoters. The Pennsylvania Railroad Management looked with favor on its construction at that time, as subaqueous tunnels, with standard railroad equipment with steam traction, were not regarded as a final or attractive solution of the problem, from the standpoint of the Management, and at a subsequent period the Pennsylvania Railroad Company agreed to use the North River Bridge provided the other roads reaching the west bank of the Hudson River would join. These roads, however, did not avail themselves of the opportunity which in its broadest scope was laid before them in 1900, after the Board of Directors of the Pennsylvania Railroad Company had approved the scheme at the instance of Mr. Cassatt.

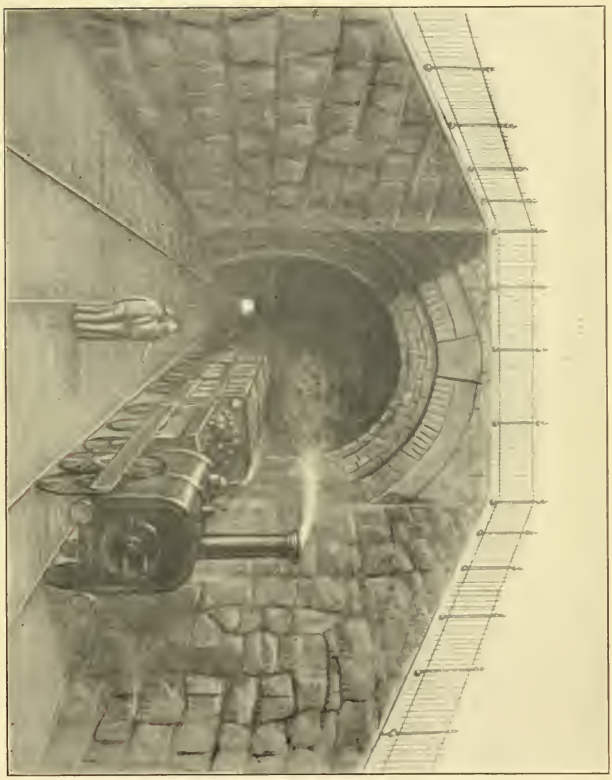
The scheme of Mr. Corbin for a subway connection, between Flatbush Avenue and the Jersey City Station of the Pennsylvania Railroad, for local transit, took form in 1892, and, jointly with the

Pennsylvania interests, railroad companies were incorporated in the respective States to build a tunnel from under the Jersey City Station, under the Hudson River to Cortlandt Street, New York City, thence under Maiden Lane, the East River, and Pineapple and Fulton Streets, Brooklyn, to a location at or near Flatbush and Atlantic Avenues. On May 9th, 1893, these companies were merged into the Brooklyn, New York and Jersey City Terminal Railroad Company, and estimates and reports on the construction were made ready by the writer in association with Mr. Rea, pending application for the franchises. The panic of 1893, occurring about that time, checked further progress on this scheme, and, before it could be revived again, other important projects for reaching New York City were given consideration.

That part of Mr. Corbin's plan contemplating a subway under Atlantic Avenue in Brooklyn to the present Flatbush Avenue Terminal was not a new idea, as a tunnel had been built in 1845 and operated under a portion of Atlantic Avenue, but later it was filled up. Plate IV, reproduced from a crayon sketch which was the property of the late William H. Baldwin, Jr., is a view of this tunnel.

In conjunction with schemes for river tunnels, complete plans for rapid transit subways for New York City, very much on the line of the present rapid transit subways, were also prepared for Mr. Corbin by the writer. These plans provided a system of deep tunnels in rock, entirely below the plane of quicksand, and at the Battery the lines were to connect directly into the tunnels to Long Island and New Jersey, respectively, and the stations throughout, where the rock was at a deep level, were to be fitted with elevators, grouped as suggested in Plate V, using private property on each side of the street at station locations—one side for north-bound and the other side for south-bound traffic. These plans were submitted to the first Rapid Transit Commission, and, after long consideration, were rejected by that Commission because they provided for the construction of the tunnels by a private company, notwithstanding Mr. Corbin gave the Commission assurances of ample financial means to carry the work to completion.

During the years 1892-93 Mr. Corbin was convinced that it was necessary to get better facilities for handling the baggage and express matter of the Long Island Railroad and the Long Island Express Company across the East River between Long Island City and New York



TUNNEL UNDER PART OF ATLANTIC AVENUE, BROOKLYN.
(From a Crayon Sketch.)

City, and he instructed the writer to investigate and report on the feasibility of building a tunnel, along the lines of the East River Gas Tunnels, then nearly completed, between the foot of East 34th Street, New York City, and the Long Island City Station of the Long Island Railroad. In 1893 an investigation was made for such a tunnel, to be of similar size to the East River Gas Tunnel (8 by 10 ft.), solely for the purpose of handling baggage and express matter. Investigation was made and estimates prepared, but the cost was considered to be prohibitive in view of the possible earnings solely from the handling of baggage and express, and the matter was not considered further.

While Mr. Corbin was deeply interested in the down-town river tunnels, the up-town situation was of great importance to the Long Island Railroad, and, having allied himself with Mr. Charles Pratt, they took up generally the franchise owned by Dr. Thomas Rainey for a bridge over Blackwell's Island. Mr. Corbin became interested with Dr. Rainey in 1894, and the actual construction proceeded on this bridge. The design provided for four railroad tracks, besides highways for tracks, pedestrians, etc., with a terminal station at Third Avenue and 64th Street, New York City, which, under the franchise, was the limit to which the railroad could proceed.

At this period there were two projects for bridging the Hudson or North River: the New York and New Jersey Bridge Company at about 59th Street, and the North River Bridge Company at 23d Street, as hereinbefore described. Several studies were made by the writer, with the idea of making a rail connection between the Long Island "Rainey" bridge and a bridge over the North River. An overhead structure connection was prohibitory, as no franchise could be obtained to cross Fifth Avenue with an overhead structure. Sketches were prepared for a subway construction to connect with the bridges, but a final plan was not worked out.

The failure to carry out the joint undertaking with the Pennsylvania Railroad Company in 1893 led Mr. Corbin to revive the scheme of extending the Long Island Railroad from Flatbush Avenue, Brooklyn, to New York City, therefore consideration was given to a relocation of the route for Mr. Corbin during the early months of 1896, the idea being that the entire up-town outlet for the Long Island Railroad would be by Blackwell's Island Bridge, and the tunnel project would give the down-town outlet.

At this time a commission had been appointed by the Legislature to investigate the conditions on Atlantic Avenue, Brooklyn, and evolve some scheme for the elimination of grade crossings on that avenue. Early in 1896 plans were prepared and presented to this Commission; first, for a subway from Flatbush Avenue Terminal for the entire distance to the limits of the City of Brooklyn at Eldert's Lane; second, for a subway from the Flatbush Avenue Terminal to East New York, Manhattan Crossing, the railroad to remain as it previously existed at grade through the 26th Ward of Brooklyn. Each of these schemes contemplated an extension through Brooklyn to New York City at Cortlandt Street and Broadway, and surveys and borings for this work were made across the East River. In the summer of 1896, on the decease of Mr. Corbin, all projects and work were immediately stopped; but, after some months, Mr. W. H. Baldwin, Jr., when elected President of the Long Island Railroad Company, took up actively the reconsideration of the means whereby the Long Island Railroad could reach New York City. After the fullest consideration, he decided that the Blackwell's Island Bridge was by no means a suitable, adequate, or convenient entry for the Long Island Railroad into New York City, as it involved too great a cost and altogether too rigid a connection; it was also a very inconvenient location, inasmuch as it was cut off from convenient access to the west side of New York City by Central Park.

For the down-town connection, Mr. Baldwin became enthusiastic, but he had in mind, throughout, the all-important necessity for the Long Island Railroad to reach the Pennsylvania Railroad across the North River. At the same time Mr. Baldwin took up energetically the Atlantic Avenue Improvement with the Atlantic Avenue Commission, and, on consideration, decided it was essential that it should extend through the 26th Ward above or below grade. The better plan, of course, was obviously to make it a subway throughout, but, further, the residents of this ward objected to the subway through that section, and that construction would have made any change of the Manhattan Beach Division at Manhattan Crossing very difficult for the future; besides this, the controlling factor was the absolute limitation by the City of Brooklyn of the amount of expenditure therefor in which they would participate, therefore a composite scheme, which is the plan as carried out, was agreed upon, being in part subway and part elevated. This scheme reached a focus

PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
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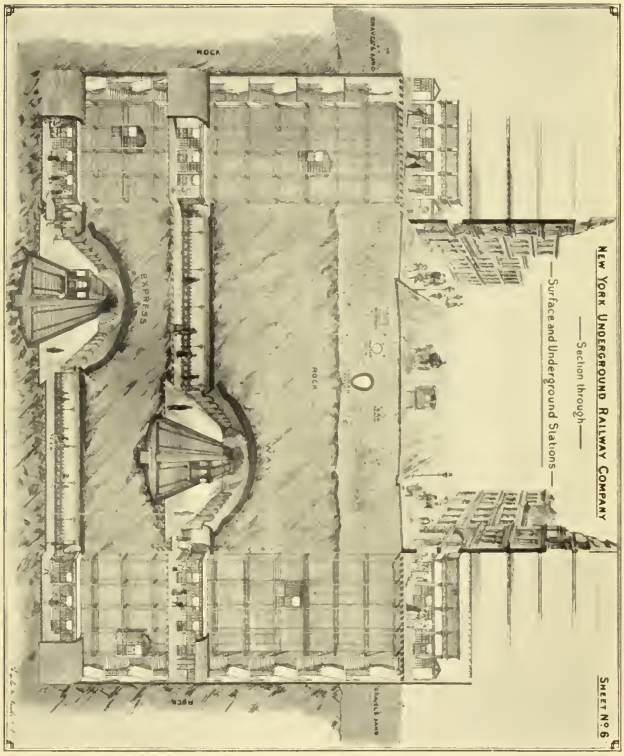
PENNSYLVANIA R. R. TUNNELS: NORTH RIVER DIVISION.



early in 1897, and the law constituting the Board for the Atlantic Avenue Improvement was passed, with a provision in the last paragraph of the Act, for the construction of a tunnel from Flatbush Avenue Terminal under Flatbush Avenue and Fulton Street to Pineapple Street, crossing the river to Broadway and Maiden Lane (Cortlandt Street), New York City, and with the understanding that it would be extended beyond the New York State Line to the Pennsylvania Railroad Station in New Jersey. This gave the legal right for the construction of this tunnel, and, on June 20th, 1899, the New York and Long Island Terminal Railroad Company was incorporated for the purpose, Mr. Baldwin being President and J. V. Davies, M. Am. Soc. C. E., Chief Engineer. Application was immediately made to the Boards of Aldermen of Brooklyn and of New York City. The latter acted favorably on the application, but the Board of Aldermen of Brooklyn held the matter up, while the Rapid Transit Commission laid out and promulgated the plan for Contract No. 2 of the Rapid Transit Subway. With the understanding that the Rapid Transit Brooklyn extension would be constructed to the Flatbush Avenue Terminal, Mr. Baldwin withdrew the application for the independent franchise, and agreed to proceed with the Atlantic Avenue Improvement, on the basis of the City proceeding with the Brooklyn extension of the Rapid Transit Subway. This provided for the Long Island Railroad entry down town.

Subsequently, however, it was proved that Mr. Baldwin had not been fully satisfied that this was the proper solution of the matter, for on April 12th, 1901, and upon his recommendation, the Board of Directors of the Long Island Railroad Company took over from the Pennsylvania Railroad Company its entire interests in the old Brooklyn, New York, and Jersey City Terminal Railway Company, thus giving him control of the route from Flatbush Avenue *via* Maiden Lane and Cortlandt Street to underneath the Jersey City station.

In the early part of 1900 active consideration was being given by the Pennsylvania Railroad and other railroads terminating in New Jersey to the proposed North River Bridge, as hereinbefore stated, and, for the Long Island Railroad, Mr. Baldwin organized a new company to construct a tunnel from the Long Island Railroad at Sunnyside Yard, diving under the streets of Long Island City by two tracks under the East River to the foot of 33d Street and

then proceeding under 33d Street as far as Seventh Avenue. A station was to be located at Fourth Avenue below the Rapid Transit Subway Station and also a large Terminal Station at Broadway. For this purpose an option was obtained on the property of the Newbold Lawrence Estate, at Broadway, Sixth Avenue, 33d and 34th Streets, now occupied by Saks' Store. Mr. Baldwin, however, considered that the amount of the investment ($1 600 000) for that property was too great for this purpose, and allowed the option to expire. The property was sold within a week thereafter to the Morganthau Syndicate for $2 000 000. At this time (May, 1900), the Pennsylvania Railroad obtained a controlling interest in the Long Island Railroad, and thereafter the two schemes became one. Mr. Baldwin and Mr. Rea purchased two 25-ft. lots on 33d Street just east of Broadway for an entrance to the underground station. Plans were also prepared for extending this line from Seventh Avenue northward under Seventh Avenue to 45th Street. The investigation and preliminary work in connection with this project were carried out in the early part of 1900.

Reconsideration was given by Mr. Baldwin to the proposed location of the up-town tunnels, with the idea of connecting the New York Central and Hudson River Railroad by a tunnel between Long Island City (Long Island Railroad Station) and the foot of 42d Street and extending to the Grand Central Station, but nothing further than investigation and the preparation of estimates was done on this.

In the summer of 1901 Mr. Cassatt was in Paris and was advised by Mr. Rea of the opening of the extension of the Orleans Railway to the Quai d'Orsay Station and its successful operation by electric power, also of the possibility of the Pennsylvania Railroad reaching New York City in a similar way (the other trunk lines not having joined in the promotion of the North River Bridge project). He at once examined the new line, and then consulted the writer in London in relation to the possibility of building tunnels under the North River. The writer returned to New York with Mr. Cassatt, and soon thereafter a conference of Mr. Cassatt, Mr. Rea, and Mr. Baldwin with the writer and Mr. Davies was held in the Pennsylvania Railroad Company Office in New York, when Mr. Cassatt outlined the scheme practically as it is now carried out, the only difference being that he also proposed a station on property of the New York and Harlem Railroad Company at 33d Street, which was soon abandoned on account of the grade from

the East River, and particularly because of the superior location of the adopted site at Seventh Avenue and 33d Street, this being central between the down-town commercial and financial district and Central Park, which divides New York City. On Mr. Cassatt's instructions, surveys and investigations were begun in November, 1901, and estimates, drawings, etc., were made. Preliminary estimates were presented to him on November 8th, 1901. Following this, borings were continued, and a plan was presented to Mr. Cassatt for assisting the support of the North River tunnels on piles, if necessary. At the time of the appointment of the Board of Engineers and the general organization of the work, the preliminary investigations and work had been carried to an advanced state.

One result of the determination of the Pennsylvania Railroad Company to extend its lines into New York City and thus move its principal station from Jersey City, was that the down-town local and suburban as well as through business was not provided for properly. Mr. William G. McAdoo, appreciating this opportunity, revived the scheme of an electric subway from Jersey City to New York, originally promoted by Mr. Corbin and associates, but not including the extension *via* Maiden Lane to Brooklyn, and entered into negotiations with the Pennsylvania Railroad Company to provide for this down-town business by extensions of the tunnel lines of the New York and New Jersey Railroads to Exchange Place, Jersey City, under the Pennsylvania Railroad Station, and thence across the Hudson River to Cortlandt and Church Streets. As a result, the Hudson and Manhattan Railroad Company was organized in 1902, and contracts were made with the Pennsylvania Railroad Company for the sub-surface use of its station in Jersey City, and for the interchange of passenger business at that point between the trains of the Pennsylvania Railroad Company and the tunnel of the Hudson and Manhattan Railroad Company. Later, a further contract was made with the Pennsylvania Railroad Company providing for the construction of the tunnel of the Hudson and Manhattan Railroad Company westward under the tracks of the Pennsylvania Railroad in Jersey City to a junction with the latter at Summit Avenue, at which point can be installed a joint station, and the operation effected of a joint electric train service between Church Street, New York City, and Newark, N. J., the Pennsylvania Railroad tracks between Summit Avenue and Newark to be electrified

for that purpose, with a transfer station established east of Newark, at Harrison, at which point the steam and electric locomotives will exchange. By means of this, all down-town passengers will transfer to the electric service at Harrison Station, and thus the Pennsylvania Railroad Company is expected to be relieved of maintaining a separate steam service for passenger traffic to Jersey City and a large down-town station with extensive contingent facilities at that point.

From the foregoing it will be seen that the final decision to extend the Pennsylvania Railroad into and through New York City by a system of tunnels, and erect a large station in that city on a most eligible site, was not reached in a hurried or off-hand manner, but after years of painstaking study and a full and extended investigation of all routes, projects, and schemes, whether originating with the company or suggested by others.

Plate VI is a map of New York City and vicinity on which are shown the various lines contemplated in the evolution of the New York Tunnel Extension of the Pennsylvania Railroad hereinbefore outlined.

The question of tunnels under the North River was an uncertain factor in the larger Pennsylvania Railroad scheme, owing to the nature of the ground composing the river bed in which the tunnels would be constructed.

It is well known that about 35 years ago an attempt was made to construct a tunnel under the North River by using a "Pilot" system under compressed air and forming the tunnels in brick masonry. Owing to the very soft nature of the materials through which it passed, several serious accidents occurred, and the work was abandoned after about 2 000 ft. of tunnel had been constructed. Later, this work was taken up again, when a shield was installed and an additional 1 800 ft. was built with cast-iron segmental lining, but the work was again abandoned, owing principally to financial difficulties while coincidentally before entering a rock reef which presented another serious difficulty in construction. The experience then in the construction of this tunnel led capitalists and engineers to believe that, owing to the very soft nature of the ground, a tunnel could not be built that would be sufficiently stable to withstand the vibration due to heavy traffic, and for this reason tunnels under the North River were not looked upon as practicable. The writer devised a scheme to carry within the tunnel the rolling loads on bridging supported on piers or piles extend-

PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD

PENNSYLVANIA RAILROAD TUNNELS
NORTH RIVER DIVISION

ENGINEERING STAFF ORGANIZATION

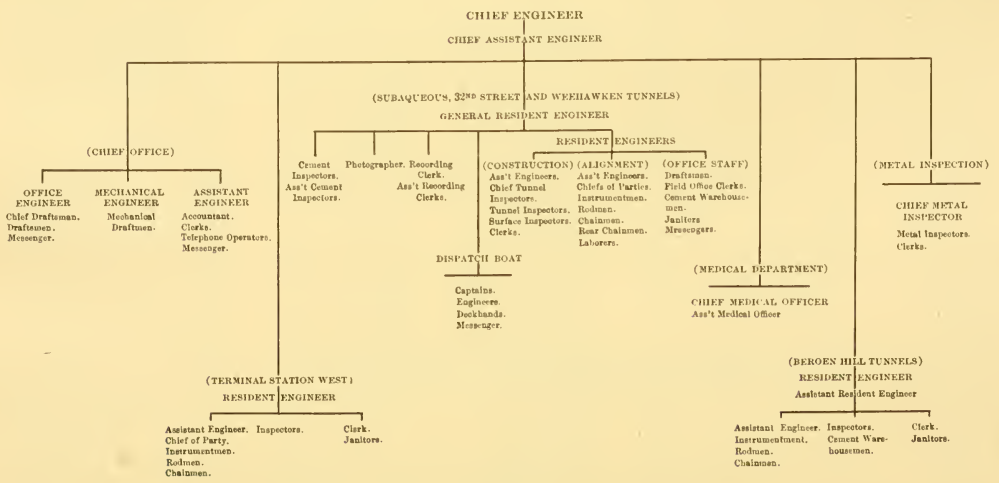


FIG. 1.

ing from the tunnel invert down to hard material. These would be attached to the tunnel itself or would pass into it independently through sliding joints in the tunnel shell. This scheme gained the confidence of the management, as it was believed that, by adopting such a plan, tunnels could be built in the soft material underlying the Hudson River and remain stable under all conditions of traffic. After thus feeling assured that by this method the tunnels could be made safe beyond question, orders were given to proceed with the great work of the extension into New York of the Pennsylvania and Long Island Railroad systems.

The organization of the engineering staff is shown on the diagram, Fig. 1. In the beginning of 1902 and during the period of making studies, additional borings, and preliminary triangulations, and prior to making the contract plans and specifications, James Forgie, M. Am. Soc. C. E., was appointed Chief Assistant Engineer by the writer. To him all the Resident Engineers and other heads of the Engineering Departments reported.

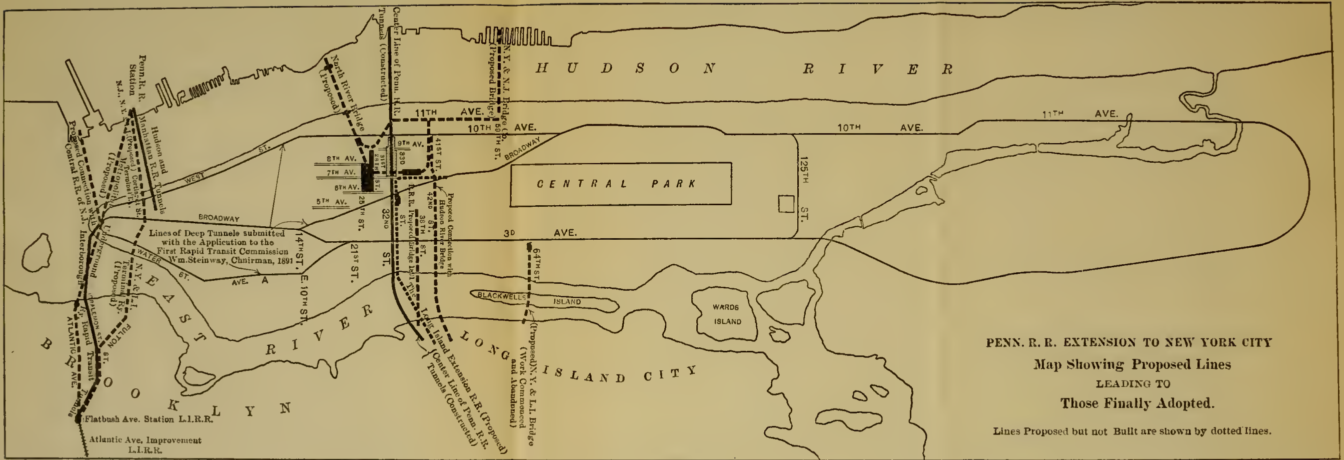
The work was divided into three Residencies:

1.—The Terminal Station-West, under the charge of B. F. Cresson, Jr., M. Am. Soc. C. E., Resident Engineer, comprising the work from the east side of Ninth Avenue to the east side of Tenth Avenue, including excavation, retaining and face walls, and the extensive work of underpinning Ninth Avenue with its surface and elevated railroads and other structures.

2.—The River Tunnels, under the charge of B. H. M. Hewett, M. Am. Soc. C. E., General Resident Engineer, and Mr. H. F. D. Burke and William Lowe Brown, M. Am. Soc. C. E., Resident Engineers, including the land tunnels from the east side of Tenth Avenue, New York City, to the commencement of the iron-lined tunnels, and extending westward from there to the Weehawken Shaft, New Jersey.

3.—The Bergen Hill Tunnels, under the charge of F. Lavis, M. Am. Soc. C. E., Resident Engineer, including the rock tunnels from the Weehawken Shaft to the Hackensack Portal on the west side of the Palisades, all in New Jersey.

Paul A. Seurot, M. Am. Soc. C. E., acted as Office Engineer in charge of the drawing office, and Mr. J. Soderberg as Mechanical Engineer in charge of the mechanical drafting. Prior to the construction of the above works Mr. C. J. Crowley acted as Resident Engineer on



PENN. R. R. EXTENSION TO NEW YORK CITY

Map Showing Proposed Lines

LEADING TO

Those Finally Adopted.

Lines Proposed but not Built are shown by dotted lines.

the construction of the Weehawken Shaft, and J. F. Rodenbough, Assoc. M. Am. Soc. C. E., on that of the Manhattan Shaft.

Table 1 shows the quantities of certain materials and other statistics regarding this Division.

TABLE 1.

	Bergen Hill.	River Tunnels.	Term. Sta.-W.
Excavation disposed of (or displaced), in cubic yards	263 000	238 995	517 000
Cast metal used in tunnel, including cast iron and cast steel, in tons	.....	64 265	.....
Steel bolts used, in tons	.....	2 606	.....
Cement used (concrete and grout), in barrels	95 000	145 500	33 000
Concrete, in cubic yards	95 000	75 400	18 500
Dynamite for blasting, in pounds	600 000	100 400	206 000
Brickwork, in cubic yards	.....	4 980	.....
Structural steel (including Pier 72), in pounds	50 000	3 141 000	1 475 000

The number of passengers carried on the Elevated Railroad and surface lines of Ninth Avenue during the underpinning of these structures was about 125 000 000.

The Board of Engineers, organized by the Pennsylvania Railroad Company in January, 1902, immediately took up the matter of route and grade. The center line, which had been assumed as the center line of 32d Street extended westward, was slightly changed.

The grade adopted was approximately 2% descending westward from Ninth Avenue, which would place the tunnel well below the Government dredging plane of 40 ft. below mean low water at the pier head line; thence westward on a lighter grade still descending until the deepest portion of the river was reached where the top of the rail would be about 90 ft. below mean high water, this location giving sufficient cover over the tunnels to insure stability and guard against the possibility of shipwrecks settling on the tunnels. From this point to the portal an ascending grade of 1.30% was adopted, which gave the lines sufficient elevation to cross over the tracks of the New York, Susquehanna and Western and the Erie Railroads, which run along the westerly base of the Palisades. Owing to the exigencies of construction, these grades in the river were very slightly modified. Plate VII is a plan and profile of the tunnels as constructed.

The Board of Engineers early in 1902 took up the question of supports for the tunnels under the North River, and various plans and

schemes were considered. It was finally decided to support the tracks on screw-piles carried through the lining of the tunnels, as originally proposed by the writer.

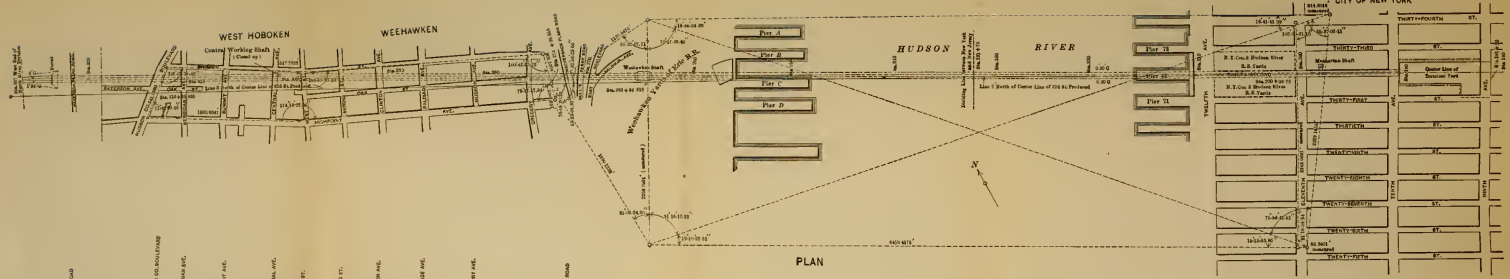
In order to know something of the capacity of screw-piles in the actual material to be passed through, it was resolved to test them. A caisson was sunk at the end of one of the Erie Railroad piers on the New Jersey side near the line of the tunnels, and, to obtain parallel conditions as much as possible, the excavation was carried down to the proposed grade of the tunnel. Various types of screw-piles were sunk therein and tests were made, not only of the dead load carrying capacity, but also with the addition of impact, when it was found that screw-piles could be sunk to hard ground and carry the required load. The final part of the test was the loading. The screw-pile, having a shaft 30 in. in diameter and a blade 5 ft. in diameter, was loaded with 600 000 lb., with the result that, for a month—the duration of this loaded test—there was no subsidence.

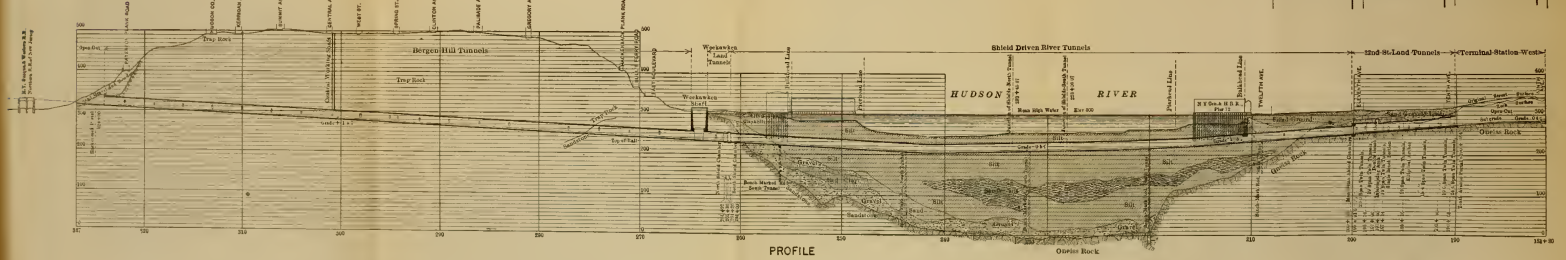
Again, and after the iron tunnel lining had been constructed across the river, tests were made of two types of supports: One a screw-pile 29½ in. in diameter with a blade 4 ft. 8 in. in diameter and the other a wrought-iron pipe 16 in. in external diameter. Tests were made, not only for their carrying capacity, but also for their value as anchorages, and it was found that the screw-pile was more satisfactory in every way; it could be put down much more rapidly, it was more easily maintained in a vertical position, and it could carry satisfactorily any load which could be placed on it as a support for the track. The 16-in. pipe did not prove efficient either as a carrier or as an anchorage. These tests will be mentioned in the detailed description of the work to follow. Figs. 2 and 3 illustrate the general arrangement and details of the machine designed by the writer and used for sinking the test piles in the tunnels. This machine had been used originally on the New Jersey side on the test pile at Pier C, and the adaption was not exactly as shown on these drawings, but if the screw-piles had been placed in the tunnels, the arrangement shown would have been used.

Surveys, soundings, and borings were commenced in the latter part of 1901 on an assumed center line of tunnels which was the center line of 32d Street extended westward.

The soundings were made from a float stage fastened to a tugboat, the location being determined by transits on shore and the elevation

PLATE VII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1151.
JACOBS ON
PENNSYLVANIA R. R. TUNNELS: NORTH RIVER DIVISION.





by measuring from the surface of the water, a tide gauge being continually observed and the time of soundings and gauge readings kept.

In the river wash-borings were made from a floating pile-driver on which was installed a diamond-drill outfit of rods, pump, etc. Fourteen borings were completed in the river. Considerable difficulty was found in holding the pile-driver against the current, the material in the bottom being very soft, and several borings were lost owing to the drifting of the pile-driver. Each boring was continued, and the depth of several was more than 250 ft. below the surface of the water. The borings on land were mostly core borings, and were generally made with the chilled shot boring machine.

Base lines, about 2 250 ft. in length, were measured on each side of the river, and observation points established. It was necessary to build a triangulation tower 60 ft. high on the New Jersey side as an observation point. The base lines were measured with 100-ft. steel tapes which were tested repeatedly, and the work was done at night in order to obtain the benefit of uniform temperature and freedom from traffic interruptions. From the base line on the New Jersey side, which passed over the Weehawken Shaft, an elevated point on the assumed center line on the side of Bergen Hill was triangulated to, and from this point westward a closed polygon was measured along the streets to the top of the hill on the west side and thence along the assumed center line to the portal. The level transfer across the river was made by sighting across in opposite directions simultaneously, and also by tide gauges. The outline of the final triangulation system is shown on Plate VII.

The decision as to the locations of the shafts on both sides of the river, for construction purposes and finally for permanent use, was a comparatively simple matter, and, all circumstances considered, they are unquestionably in the most suitable places. On the New York side the shaft was as near as practicable to the line dividing the subaqueous iron-lined tunnels from the land tunnels, and on the New Jersey side the shaft was placed centrally on the line of the tunnels and on the nearest available ground to the river, while at the same time beyond the other end of the river tunnels, thus necessitating driving the subaqueous tunnels only from east and west to meet under the river. A caisson shaft on the New York side, on the line of the tunnels near the river bulkhead, was at one time considered, but was not

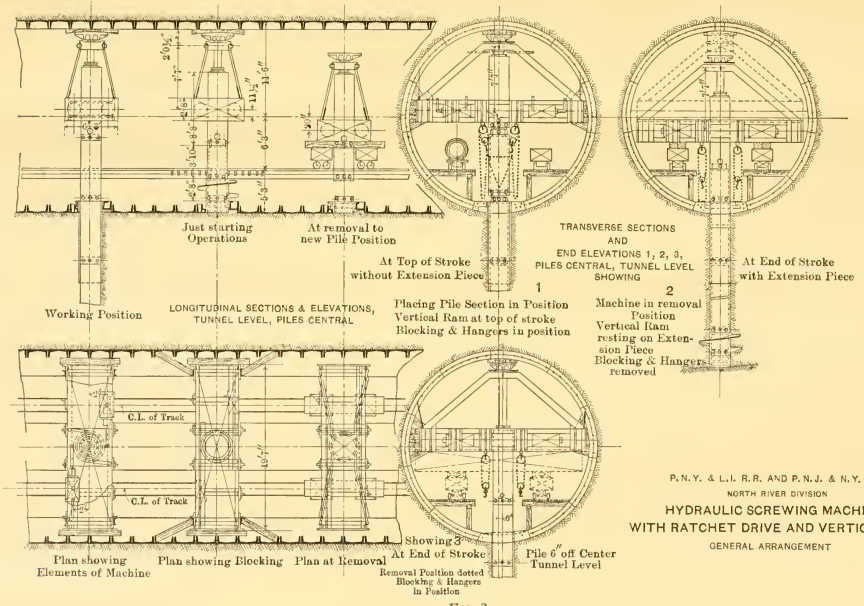
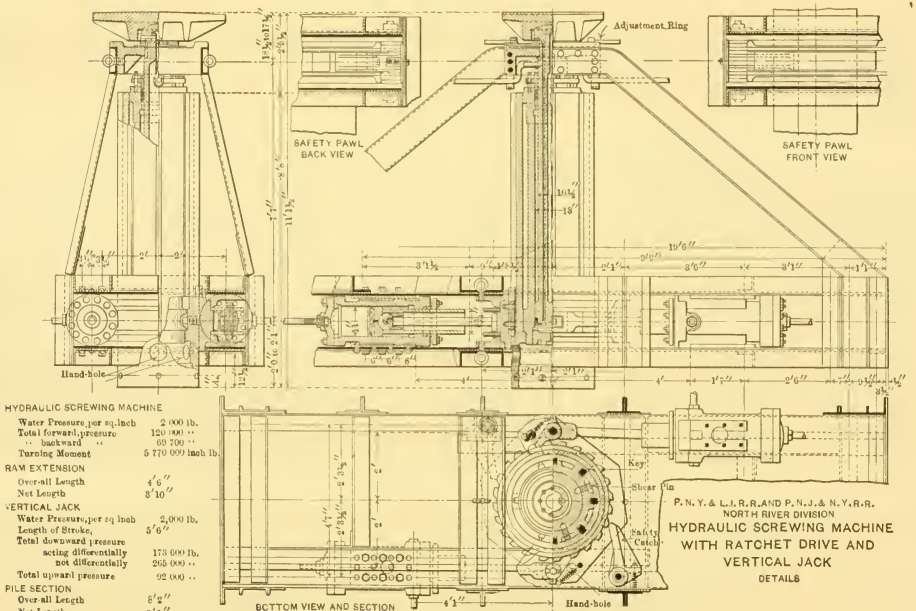

Just starting Operations
At removal to new Pile Position
At Top of Stroke without Extension Piece
TRANSVERSE SECTIONS AND END ELEVATIONS 1, 2, 3, PILES CENTRAL, TUNNEL LEVEL SHOWING
At End of Stroke with Extension Piece
Working Position
LONGITUDINAL SECTIONS & ELEVATIONS, TUNNEL LEVEL, PILES CENTRAL
Placing Pile Section in Position Vertical Ram at top of stroke Blocking & Hangers in position
1
2
Machine in removal Position Vertical Ram resting on Extension Piece Blocking & Hangers removed
C.L. of Track
C.L. of Track
Showing 3
Plan showing Elements of Machine
Plan showing Blocking
Plan at Removal
At End of Stroke
Removal Position dotted Blocking & Hangers in Position
Pile 6″ off Center Tunnel Level
P.N.Y. & L.I. R.R. AND P.N.J. & N.Y. R.R.
NORTH RIVER DIVISION
HYDRAULIC SCREWING MACHINE
WITH RATCHET DRIVE AND VERTICAL JACK
GENERAL ARRANGEMENT

FIG. 2.



HYDRAULIC SCREWING MACHINE

Water Pressure, per sq. inch	2 000 lb.
Total forward pressure	120 000 "
" backward "	60 200 "
Turning Moment	5 770 000 inch lb.

RAM EXTENSION

Over-all Length	4′6″
Net Length	3′10″

VERTICAL JACK

Water Pressure, per sq inch	2,000 lb.
Length of Stroke,	5′6″
Total downward pressure acting differentially	173 000 lb.
not differentially	265 000 "
Total upward pressure	92 000 "

PILE SECTION

Over all Length	5′2″
Net Length	3′6″
Diameter of Pile	2′5¾″

FIG. 3.

adopted as it entailed the driving of two shields both east and west, in addition to the two from New Jersey, adding to the plant outlay while not affording any material saving in the time of construction.

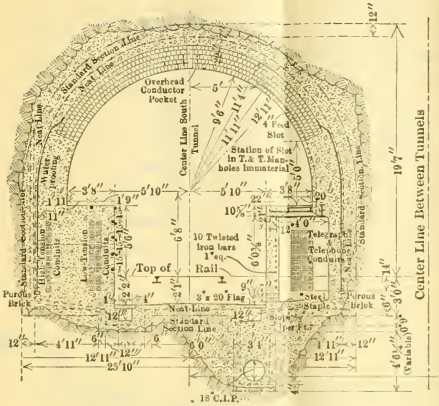
It was thought desirable to construct the shafts on the two sides of the river in advance of letting the main contracts for the tunnels. The Manhattan Shaft is north of the line of the tunnels, on the north side of 32d Street, east of Eleventh Avenue. The Weehawken Shaft is on the line of the tunnels in the yards of the Erie Railroad on the New Jersey side, and the distance between the shafts is about 6 575 ft. The contracts for these shafts were let in June, 1903, to the United Engineering and Contracting Company, and they were completed and ready for use at the time of letting the main contract for the tunnels, thus saving considerable time.

The Terminal Station-West.—Between Ninth and Tenth Avenues. —In the original design it was contemplated to have a four-track tunnel under 32d Street from Ninth to Eleventh Avenues, but owing to the necessity for having additional yard facilities, property was bought for about 100 ft. north and 100 ft. south of 32d Street, between Ninth and Tenth Avenues, and an open excavation, lined with concrete retaining walls and face walls, was made. Between Ninth and Tenth Avenues, 32d Street was closed, and the property formerly the street was bought by the Tunnel Company from the City of New York for a consideration by deed dated April 18th, 1906. The Church, Rectory, and School of St. Michael's, which was located on the west side of Ninth Avenue between 31st and 32d Streets, was acquired by the Tunnel Company after it had acquired property for and had built a similar institution on the south side of 34th Street west of Ninth Avenue.

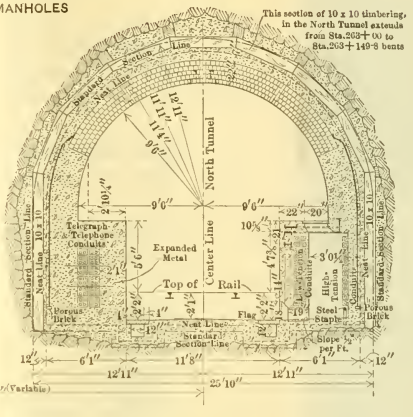
Probably the most interesting feature of this contract was the support and maintenance of Ninth Avenue, which has a three-track elevated railway structure and a two-track surface railway structure, on which it was necessary to maintain traffic while excavation was made to a depth of about 60 ft., and a viaduct was erected to carry Ninth Avenue. The length of this viaduct is about 375 ft., and the steelwork and its erection was done apart from the North River Division work, but all excavation and underpinning was included in this division. The contract for this work on the Terminal Station-West was let to the New York Contracting Company-Pennsylvania

WEEHAWKEN TUNNELS

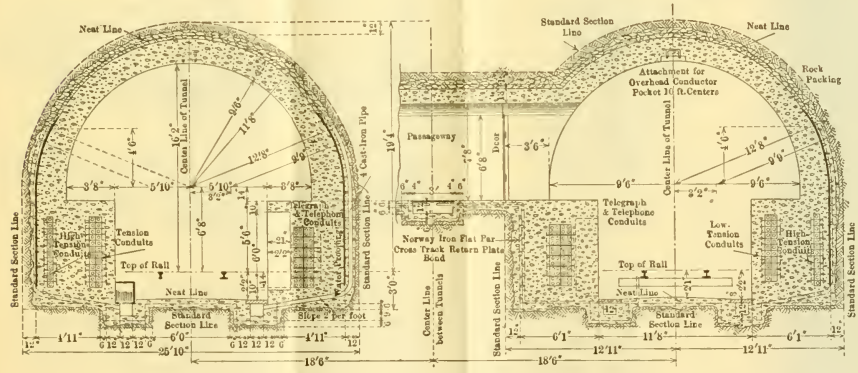
CROSS-SECTION AT MANHOLES

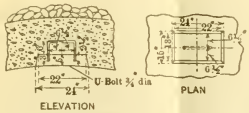


CROSS-SECTION THROUGH T. & T. MANHOLE
Sta. 262+75



CROSS-SECTION THROUGH HIGH TENSION MANHOLE
Sta. 263+00





U-BOLT ATTACHMENT FOR OVERHEAD CONDUCTOR POCKET

PENNSYLVANIA, NEW JERSEY AND NEW YORK RAILROAD CO.
NORTH RIVER DIVISION

BERGEN HILL TUNNELS

TYPICAL SECTION BETWEEN MANHOLES

Terminal, on April 28th, 1906, and included about 517 000 cu. yd. of excavation, about 87% being rock, the construction of about 2 000 lin. ft. of retaining and face walls containing about 18 500 cu. yd. of concrete, and a large quantity of structural steel (1 475 000 lb.) for temporary use in underpinning Ninth Avenue.

Fig. 4 shows cross-sections of the Terminal Station-West yard, and Fig. 5 shows the general method of underpinning the Ninth Avenue structures.

River Tunnels.—In the original plan a four-track tunnel was contemplated from the east side of

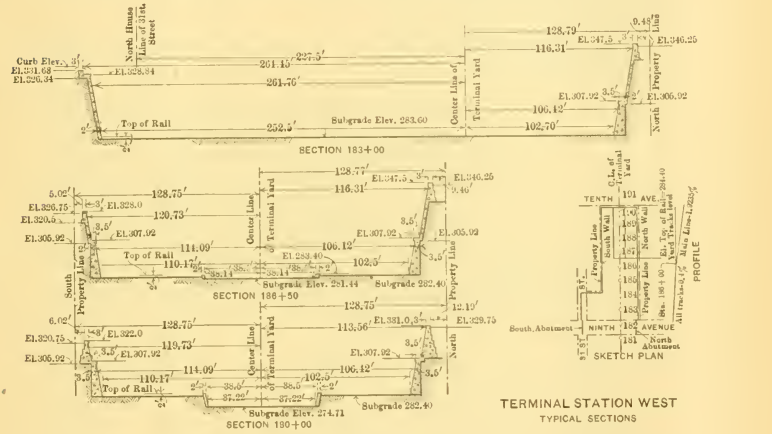


FIG. 4.

Eleventh Avenue, but, owing to the extension of the Terminal Yard, previously noted, this plan was changed, and a two-track structure was built having a central wall between the tracks. This was constructed in tunnel, with the exception of 172 ft. about midway between Tenth and Eleventh Avenues, where the rock dipped below the roof of the tunnel, and there the construction was made in open cut. These tunnels were lined with concrete with brick arches, Figs. 6, 7, and 8 being typical cross-sections. This work was executed by the O'Rourke Engineering Construction Company, under a contract dated November 1st, 1904.

It was possible to excavate in full rock cover about 250 ft. of the tunnels eastward from the Weehawken Shaft and 225 ft. westward from the Manhattan Shaft. At these points the rock cover was very thin, and there shield chambers were made for the erection of two sets of shields, about 6 100 ft. apart. A typical cross-section of the Weehawken Land Tunnel is shown on Plate VIII.

The Board of Engineers decided, and it was so stated in the contract and specifications, that the river tunnels should be constructed by means of hydraulic shields, but bidders were permitted to present to the Board any scheme on which they might desire to bid, but, of course, the decision as to the practicability of such plans rested with the Board.

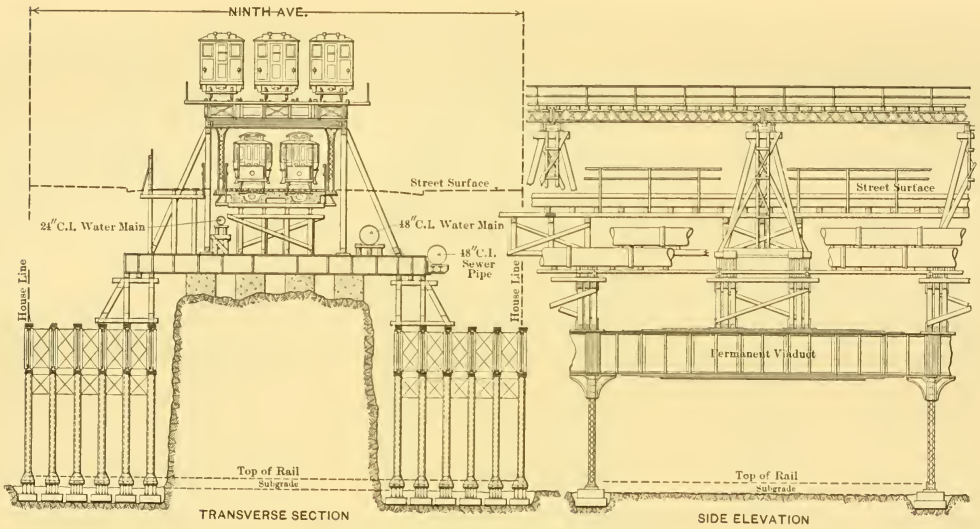
Inasmuch as the shield method of construction was required, the writer designed a shield for use in the North River Tunnels. The shield was about 18 ft. long, over all, and was provided with a rigid but removable hood extending beyond the normal line of the cutting edge, for use in sand, gravel, and ballast, to be removed when the shield reached the silt. The shields were thrust forward by twenty-four rams capable of exerting a pressure of 3 400 tons at a hydraulic pressure of 5 000 lb. per sq. in. Taking into account 30 lb. air pressure, this pressure was increased to 4 400 tons. The shield was fitted with a single hydraulic erector and hydraulic sliding platforms, and when complete weighed 194 tons. Fig. 9 is a back elevation and section of the shield.

The contract for the river tunnels was let to the O'Rourke Engineering Construction Company on May 2d, 1904.

The shields were built in accordance with the design previously referred to, and proved entirely satisfactory. Generally, the materials passed through were as follows: Starting out in full face rock, from it into a mixed face of rock and sand, thence into sand and gravel, full face of sand, piles, rip-rap, and the Hudson silt; and all were fully charged with water.

Compressed air, at an average gauge pressure of about 25 lb. and a maximum of 40 lb. per sq. in., was used in the tunnels from the time the shields emerged from full rock face until the tunnel lining had been joined up and all caulking and grummeting had been done.

Contractor's plants were established at the Weehawken Shaft and at the Manhattan Shaft, including at each, low-pressure air compressors



PENNSYLVANIA TUNNEL & TERMINAL RAILROAD CO.
NORTH RIVER DIVISION
TERMINAL STATION WEST
ARRANGEMENT OF STRUCTURES SUPPORTING
NINTH AVE. DURING PROGRESS OF EXCAVATION
FIG. 5.

of a capacity of 13 000 cu. ft. of free air per minute and also high-pressure air compressors for drills, hydraulic pumps, electric generators, etc.

The river tunnels passed under Pier 72, North River (old No. 62), which was occupied by the New York Central and Hudson River Railroad Company. The Tunnel Company leased this pier and withdrew all the piles on the lines of the tunnels prior to the commencement of construction, and on the remaining piles constructed a trestle for the disposal of the excavation from the tunnels and the terminal. At the completion of the work this pier had to be restored, and Fig. 10 shows the general arrangements of the location of the piles and the pier structure with reference to the tunnels.

In the tunnels which were constructed in silt farther down the river, by the writer as Chief Engineer for the Hudson Companies, it had been possible to shove the shield through the silt with all the doors closed, displacing the ground and making great speed in construction owing to the absence of all mucking. It was thought that this procedure might be pursued in the larger tunnels of the Pennsylvania Railroad, and it was tried, but it was almost immediately found to be impossible to maintain the required grade without taking a certain quantity of muck into the tunnels through the lower doors, the tendency of the shield being to rise. By taking in about 33% of the excavation displaced by the tunnel, the grade could be maintained. It was considered desirable, owing to this rising of the shields, to increase the weight of the cast-iron lining, and this was done, making the weight of the completed tunnel more nearly equal to the weight of the displaced material. The weight of the cast-iron lining (with bolts) was increased from 9 609 to 12 127 lb. per lin. ft. of tunnel. The weight of the finished tunnel with this heavier iron is 31 469 lb. per lin. ft. The weight of the silt displaced per linear foot of tunnel, at 100 lb. per cu. ft., is 41 548 lb. The weight of the completed tunnel with the maximum train load is 42 869 lb. per lin. ft.

The maximum progress at one face in any one month was 545 ft., working three 8-hour shifts, and the average progress in each heading while working three shifts was 18 ft. per 24 hours; while working one shift with the heavier lining referred to above, the delivery of which was slow, the average progress was 11 ft. per 24 hours.

In order to permit the screw-piles to be put in place through the

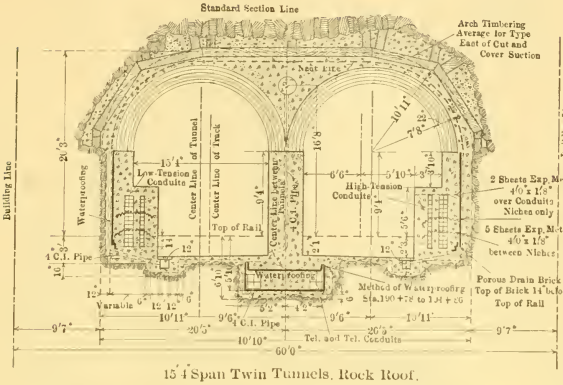


FIG. 6.

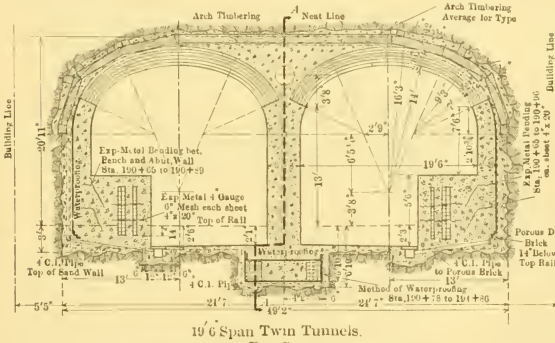


FIG. 7.

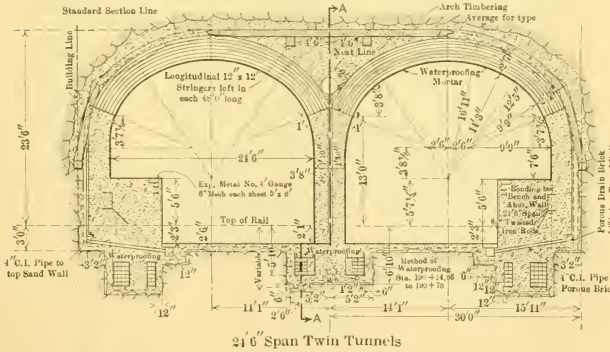
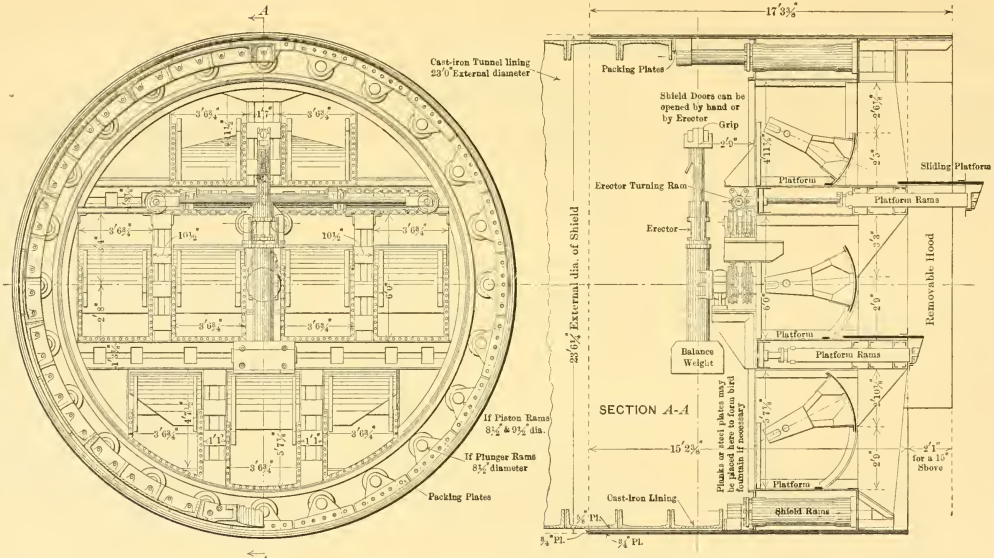


FIG. 8.



PROPOSED SHIELD FOR SUBAQUEOUS TUNNELING
GENERAL ELEVATION

FIG. 9.

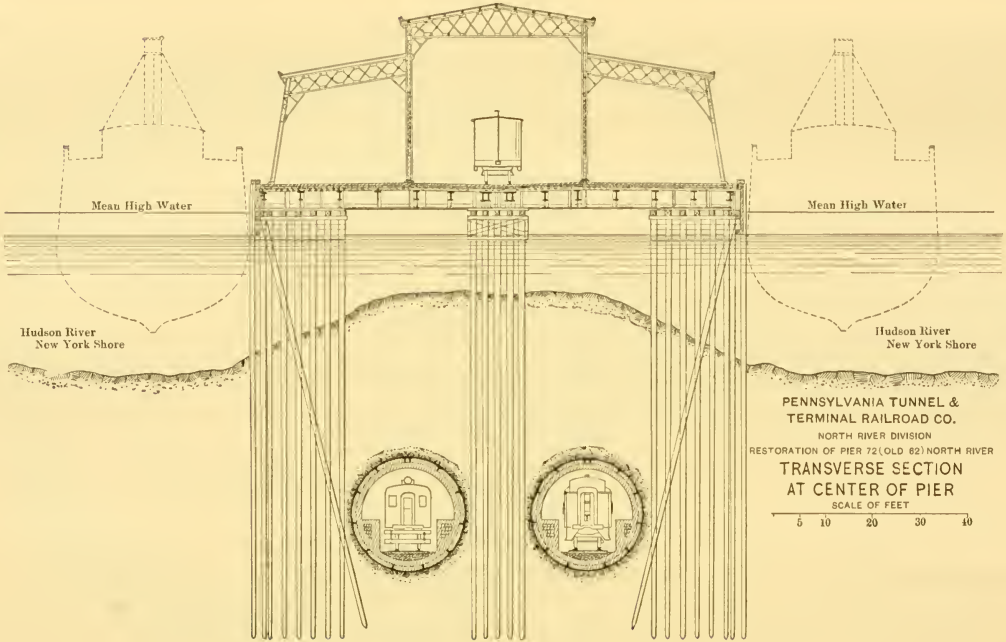
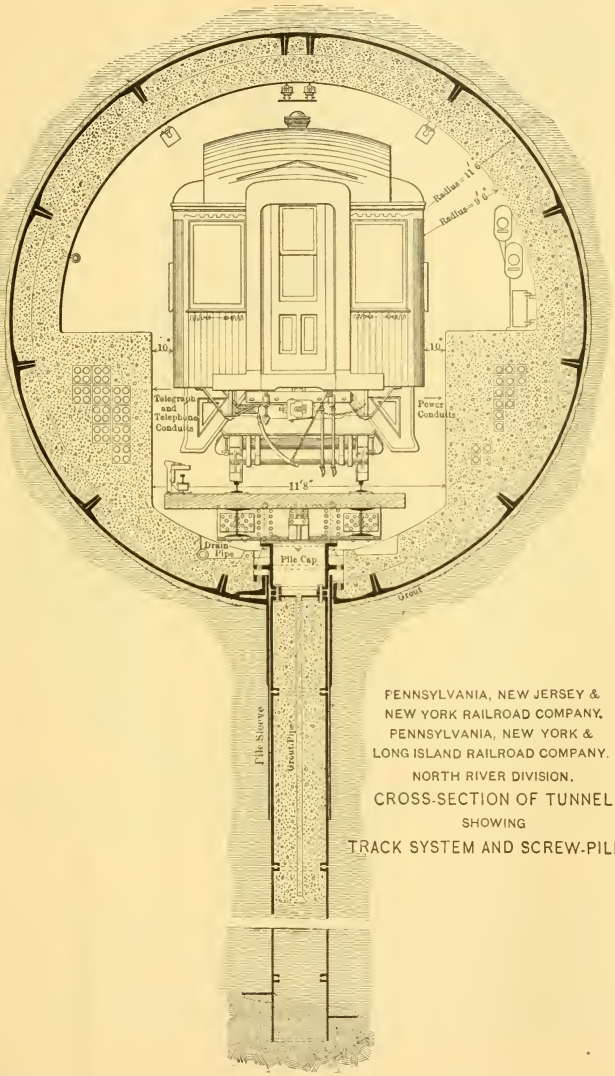

Mean High Water
Mean High Water
Hudson River
New York Shore
Hudson River
New York Shore
PENNSYLVANIA TUNNEL &
TERMINAL RAILROAD CO.
NORTH RIVER DIVISION
RESTORATION OF PIER 72 (OLD 62) NORTH RIVER
TRANSVERSE SECTION
AT CENTER OF PIER
SCALE OF FEET
5 10 20 30 40

FIG. 10.

lining, cast-steel bore segments were designed, and placed in the invert at 15-ft. centers; these are of such a design as to permit the blade and shaft of the screw-pile to be inserted without removing any portion of the lining. Fig. 11 is a typical cross-section of the river tunnel, as originally planned, with these pile supports.

After the shields had met and the iron lining was joined up, various experiments and tests were made in the tunnel; screw-piles, and 16-in. pipes, previously referred to, were inserted through the bore segments in the bottom of the tunnel, thorough tests with these were made, levels were observed in the tunnels during the construction and placing of the concrete lining, an examination was conducted of the tunnels of the Hudson and Manhattan Railroad Company under traffic, and the result of these examinations was the decision not to install the screw-piles. The tunnels, however, were reinforced longitudinally by twisted steel rods in the invert and roof, and by transverse rods where there was a superincumbent load on the tunnels; it might also be noted that on the New York side, where the tunnels emerge from the rock and pass into the soft material, the metal shell is of cast steel instead of cast iron. Fig. 12 is a typical cross-section of the river tunnels as actually constructed.

During the investigations in the tunnels, borings were made to determine exactly the character of the underlying material, and it was then found that the hard material noted in the preliminary wash-borings was a layer of gravel and boulders overlying the rock. When the borings in the tunnels reached this material it was found to be water-bearing and the head was about equivalent to that of the river. Rock cores were taken from these borings, and the deepest rock was found at about the center of the river at an elevation of 302.6 ft. below mean high water. Rods were then inserted in each bore hole and thereby attached to the rock and used as bench-marks in the tunnels. From these bench-marks, using specially designed instruments, very accurate observations of the behavior of the tunnels could be made, and from these the very interesting phenomenon of the rise and fall of the tunnels with the tide was verified, the tunnels being low at high tide and the average variations being about 0.008 ft. in the average tide of about 4.38 ft.: the tidal oscillations are entirely independent of the weight of the tunnels, since observations show them to have been the same both before and after the concrete lining was in position. There was



PENNSYLVANIA, NEW JERSEY & NEW YORK RAILROAD COMPANY.
PENNSYLVANIA, NEW YORK & LONG ISLAND RAILROAD COMPANY.
NORTH RIVER DIVISION.
CROSS-SECTION OF TUNNEL
SHOWING
TRACK SYSTEM AND SCREW-PILE.

FIG. 11.

considerable subsidence in the tunnels during construction and lining, amounting to an average of 0.34 ft. between the bulkhead lines. This settlement has been constantly decreasing since construction, and appears to have been due almost entirely to the disturbances of the surrounding materials during construction. The silt weighs about

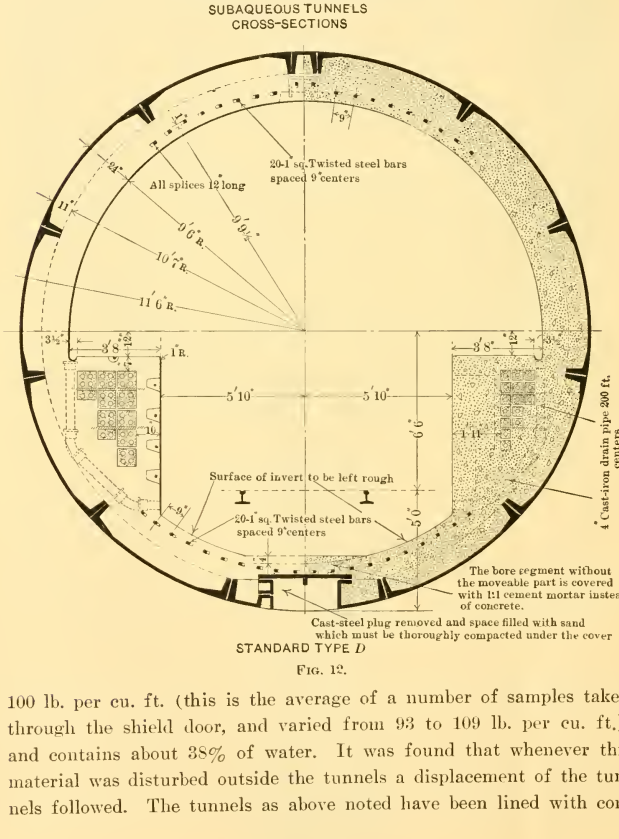


FIG. 12.

100 lb. per cu. ft. (this is the average of a number of samples taken through the shield door, and varied from 93 to 109 lb. per cu. ft.), and contains about 38% of water. It was found that whenever this material was disturbed outside the tunnels a displacement of the tunnels followed. The tunnels as above noted have been lined with con-

crete reinforced with steel rods, and prior to the placing of the concrete the joints were caulked, the bolts grummeted, and the tunnels rendered practically water-tight; the present quantity of water to be disposed of does not exceed 300 gal. per 24 hours in each tunnel 6 100 ft. long.

Bergen Hill Tunnels.—These are two single-track tunnels, 37 ft. from center to center, and extend for a distance of 5 940 ft. from the Weehawken Shaft to the Hackensack Portal. They were built almost entirely through trap rock. The contract was let on March 6th, 1905, to the John Shields Construction Company, but was re-let on January 1st, 1906, to William Bradley, the Shields Company having gone into the hands of a receiver. About 1 369 ft. of the tunnel excavation was done by the Shields Company, but no concrete lining. The maximum monthly progress for all headings was 622 ft., and the average progress was 338 ft. A working shaft 216 ft. deep was sunk from the top of the hill, to facilitate construction. The tunnels are lined with concrete throughout. Typical cross-sections of these tunnels are shown on Plate VIII.

In conclusion it may be admissible for the writer after having, in conjunction with Mr. Samuel Rea, experienced the evolution and materialization of this Pennsylvania Railroad scheme, to express his great sorrow for the untimely death of the father of the entire scheme, the late President Cassatt.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1152

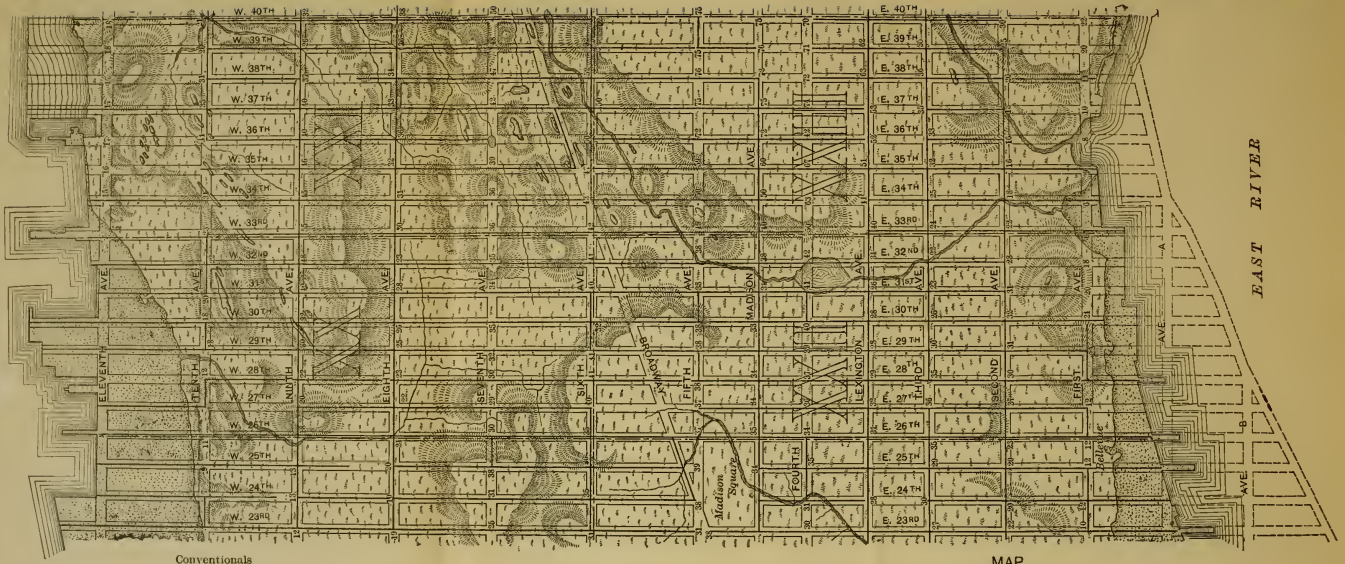
THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE EAST RIVER DIVISION.

By Alfred Noble, Past-President, Am. Soc. C. E.

A general outline of the work included in this Division has been given by General C. W. Raymond, M. Am. Soc. C. E., in the first paper of the series. The few pages following are intended only as a note to connect his paper with the more detailed descriptions of the execution of the work, which will be supplied by the Resident Engineers in immediate charge.

Soon after the Company's project was made public, in the latter part of 1901, borings were begun in the East River, and a few weeks later in Manhattan and Long Island City. A preliminary base line was measured on the Manhattan side, and temporary transit stations were established on buildings from which all borings in the river were located. The river borings were all wash-borings made from a pile-driver boat. After the results were plotted on the map, contour lines were drawn to indicate the rock surface, and profiles along the tunnel lines were plotted from the contours; as the borings were preliminary to the final location of the tunnels, and in many cases at some distance from the tunnel lines, considerable divergence from the actual rock surface was expected, and realized in a few places, yet on the whole the agreement was very good. The borings revealed two depressions or channels where the rock surface passed below the grade of the projected tunnels, these depressions being separated by a rock reef which extends down stream from Blackwell's Island. In 32d and 33d

PLATE IX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1152.
NOBLE ON
PENNSYLVANIA R. R. TUNNELS: EAST RIVER DIVISION.



Conventionals

Made Land

Meadow Land

Sewers

SCALE OF FEET

0 500 1000 2000

MAP
OF PORTION OF
MANHATTAN ISLAND
FROM 23D TO 40TH STREETS,
SHOWING FORMER TOPOGRAPHY
FROM MAP MADE BY
GEN. EGBERT L. VIELE
IN
1865

Streets in Manhattan, borings were made from the river to the station site at intervals of about 100 ft., wash-borings and core-borings alternating. In Long Island City, where the tunnel lines were to pass diagonally under the passenger station building and passenger yard of the Long Island Railroad and under streets and private property, the arrangement of borings was less regular, although the alternation of wash-borings and core-borings was carried out as far as practicable. After the final location of the work, additional borings were made, particularly on shaft sites and also along the approaches and in the Sunnyside Yard, Long Island City.

A triangulation was carried across the river with a measured base on each side. It was impossible to measure directly between the extremities of either base. The bases were measured with 100-ft. steel tapes, supported every 20 ft., stretched with a uniform pull, and frequently compared with standardized tapes. On account of the crowded condition of the streets during the hours of daylight and evening, most of the work was done between 10 P. M. and 5 A. M. Similar measurements were made in the streets along the tunnel lines. Angle readings were repeated many times, as is usual in such work. Fig. 1 shows the triangulation, the street measurements being omitted.

Levels were first transmitted across the river by simultaneous observations of the river surface; then by several repetitions, across Blackwell's Island and the narrow channels on each side, where the longest sights were about 1 100 ft.; and, finally, by several lines through the tunnel of the East River Gas Company at 71st Street.

The franchise granted by the City of New York provided for the sale to the Railroad Company of the portions of 32d Street between Seventh and Eighth Avenues, and between Eighth and Ninth Avenues. Later, the Company acquired by purchase the portion of 32d Street between Ninth and Tenth Avenues. The franchise granted sub-surface rights under streets around the station site to within 19 ft. of the street surface under Seventh, Eighth, and Ninth Avenues; to within 30 in. of the street surface under 31st and 33d Streets, except that, under the sidewalks opposite the station, that is to say, the south sidewalk in 31st Street and the north sidewalk in 33d Street, the construction must be at least 5 ft. below the street surface. In carrying out the work, full use of these rights was made under Eighth Avenue, but only under such portions of Seventh and Ninth Avenues as were

indispensable for access by trains to the station area. It was not practicable to make full use of the rights granted under 31st and 33d Streets without incurring great expense for supporting adjacent buildings or for injuries to them, and, after careful consideration, the arrangement shown in the plans was decided on, making about 45% of the sub-surface area under these streets available at track level.

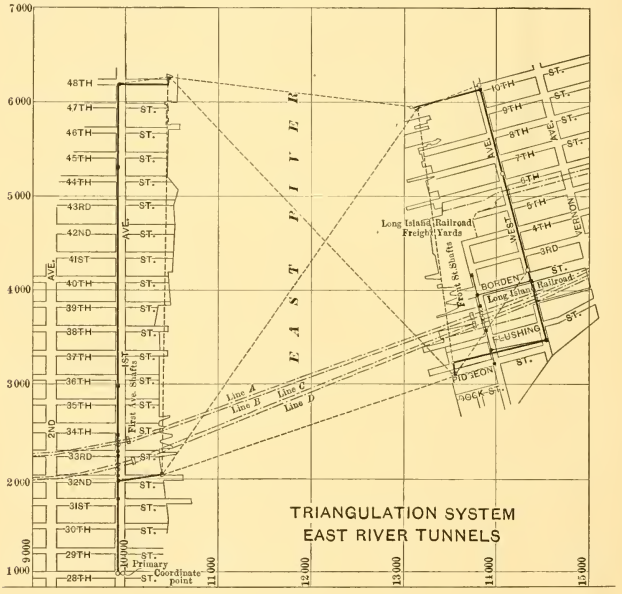
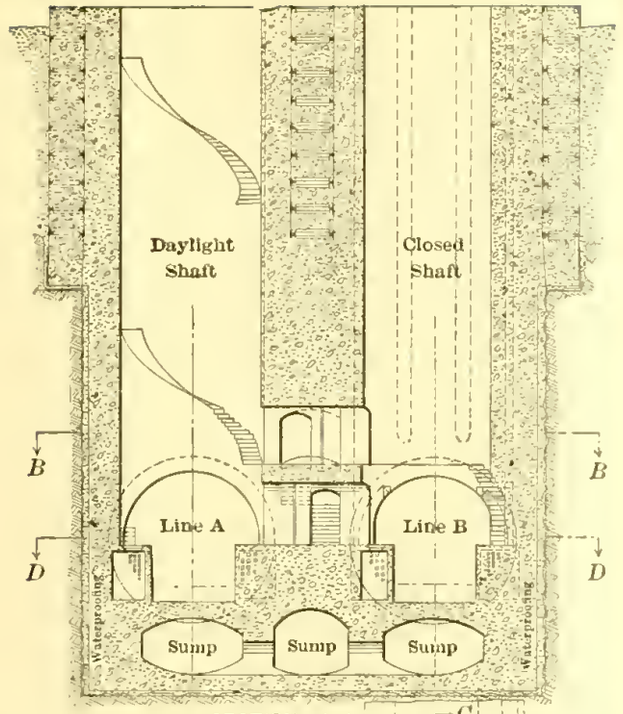


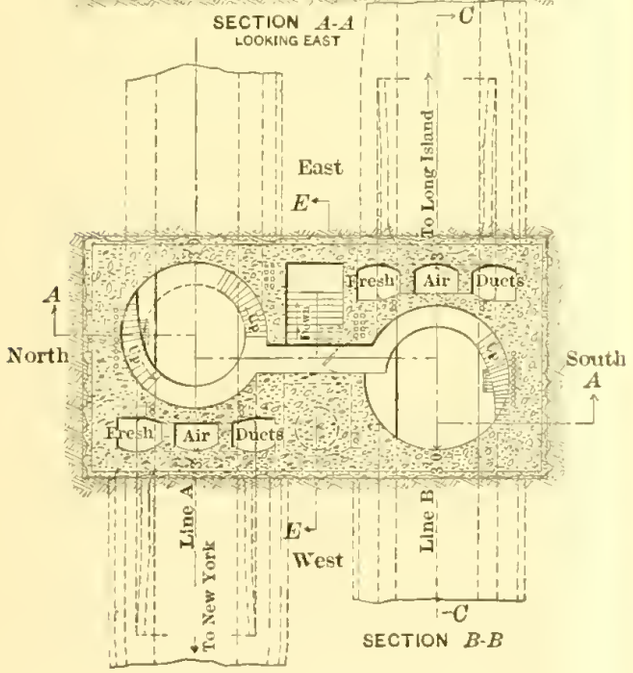
FIG. 1.

The work of the East River Division at this site embraced the excavation to the depth necessary for railroad tracks, and the building of a retaining wall extending in 31st Street from the east side of Ninth Avenue to the west side of Seventh Avenue, thence northward along Seventh Avenue for a distance of 155.5 ft.; also a retaining wall in 33d Street from the west side of Seventh Avenue to the east side of Ninth Avenue, and thence southward along Ninth Avenue for a distance of 136.3 ft. This work was placed under contract June 21st,

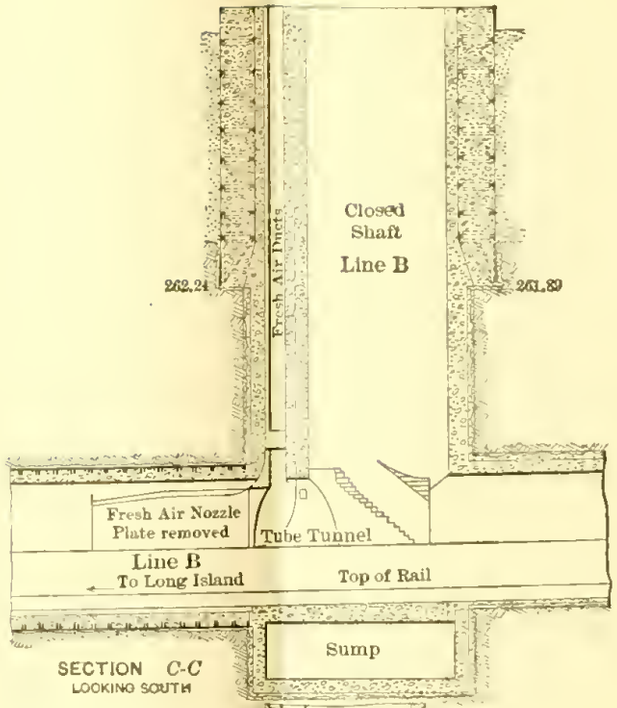
PLATE X.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1152.
NOBLE ON
PENNSYLVANIA R. R. TUNNELS: EAST RIVER DIVISION.



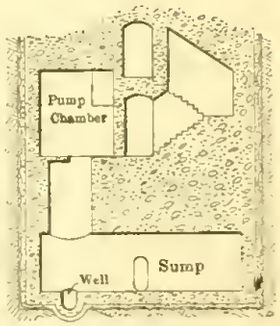
SECTION *A-A*
LOOKING EAST



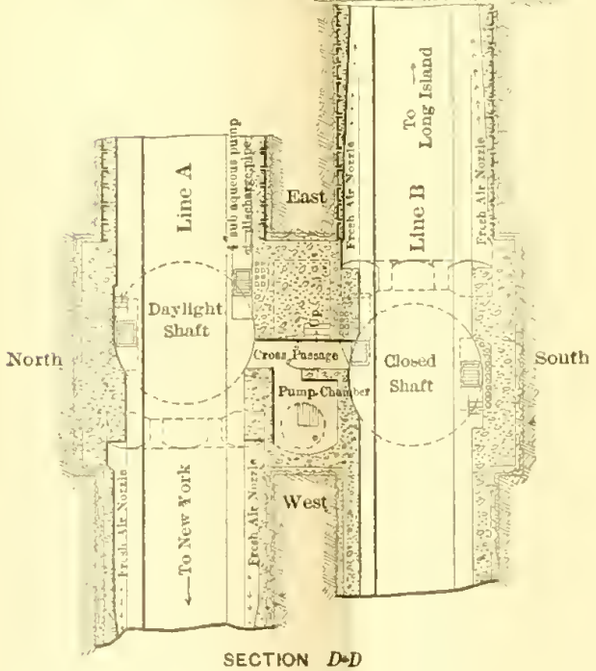
SECTION *B-B*



SECTION *C-C*
LOOKING SOUTH



SECTION *E-E*
LOOKING NORTH



SECTION *D-D*

MANHATTAN SHAFT
LINES *A* AND *B*

1904, with the New York Contracting and Trucking Company, and later assigned by that company to the New York Contracting Company-Pennsylvania Terminal, and was carried out under the direction of George C. Clarke, M. Am. Soc. C. E., as Resident Engineer, by whom it will be described in detail.

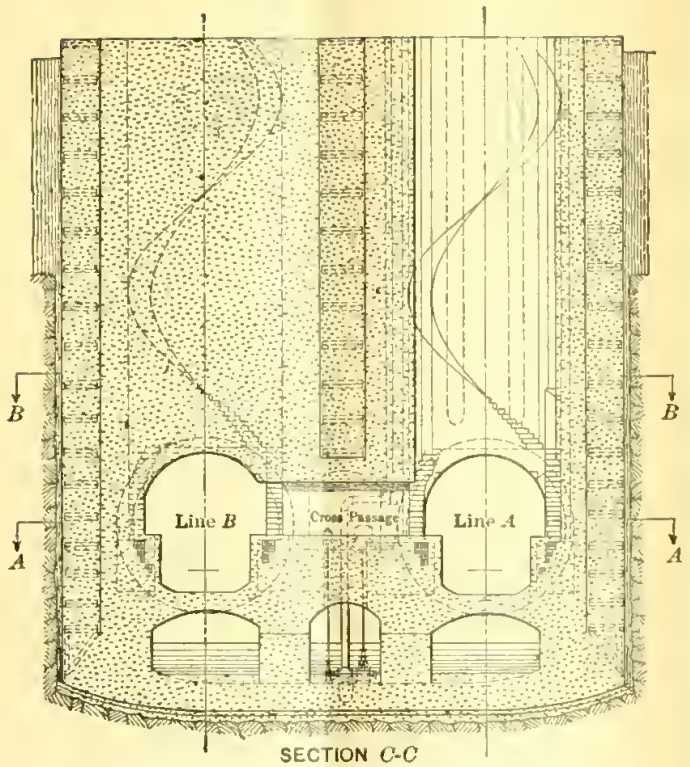
The station tracks leading eastward from the station will converge under Seventh Avenue and for some distance farther east, and pass into two three-track tunnels, one under 32d Street and the other under 33d Street, at the respective distances of 192 and 402 ft. from Seventh Avenue. A typical cross-section of the three-track tunnel is shown on Plate XII. The converging sections were considered as easterly extensions of the station, and were not included in the East River Division. Within a few hundred feet (Plate XIV), the tracks are reduced to two, each passing into a single tube, the two tunnels under each street being formed in one excavation, the distance between center lines of tunnels being 20 ft. 4 in. This construction has been termed a twin tunnel, and a typical cross-section is shown on Plate XII. The tunnels continue on tangents under the streets to Second Avenue where they curve to the left by 1° 30′ curves, passing under private property, gradually diverging and passing through shafts just east of First Avenue. About 350 ft. west of the shaft, the divergence of the two lines from each street becomes sufficient to leave a rock dividing wall between them, and thence eastward each tunnel is formed in a separate excavation. A typical cross-section of the two separated tunnels is shown on Plate XII.

It thus appears that eastward from the station the lines constitute a four-track railroad, each track being in a separate tunnel; for convenience of the work these lines were designated *A, B, C,* and *D,* from north to south.

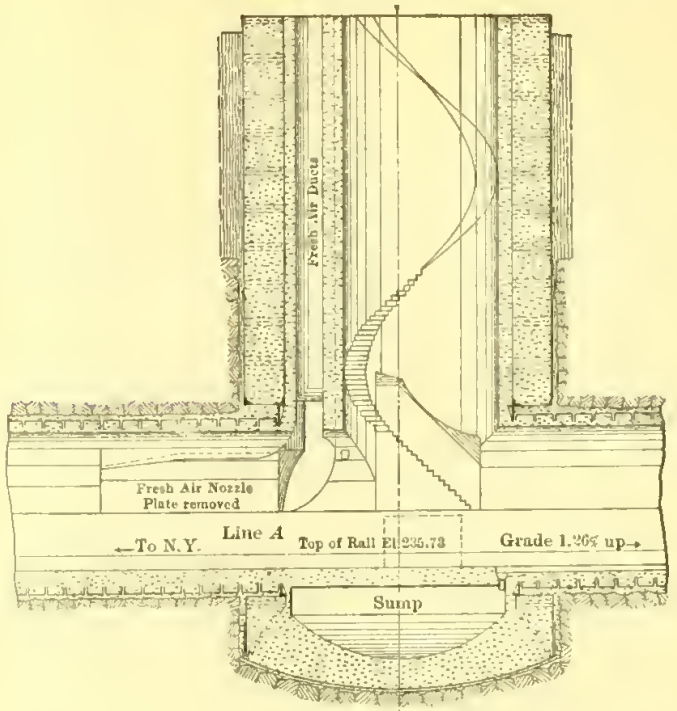
At an early date, when the organization of the engineering staff was taken up, Charles L. Harrison, M. Am. Soc. C. E., was appointed Principal Assistant Engineer. He was directly in charge of all parts of the work, and all Resident Engineers reported to him. George Leighton, M. Am. Soc. C. E., was placed in charge as Resident Engineer of the 33d Street lines from the west end of the three-track tunnel to the shaft and also eastward from the shaft under East River. As he was not then able to endure the effects of compressed air, the work under the river was transferred to James H. Brace, M. Am. Soc. C. E.,

as Resident Engineer. Before the completion of the land tunnels under 33d Street, Mr. Leighton accepted more responsible employment elsewhere, and Mr. Brace assumed charge of them also. Francis Mason, M. Am. Soc. C. E., was in charge as Resident Engineer of the 32d Street lines during their entire construction, and also of the tunnels extending these lines eastward from the First Avenue shaft under the river.

The work just described as the 32d and 33d Street lines, terminating at the easterly end at the First Avenue shafts, was placed under contract on May 29th, 1905, with the United Engineering and Contracting Company. The plans then provided for three-track tunnels from the west end of the work under the contract eastward 1 628 ft. in 32d Street and 1 418 ft. in 33d Street to the west line of Fifth Avenue, with a descending grade of 0.4%; this was to constitute, in a degree, an extension of the station, where trains could stand without brakes while awaiting signals to proceed to or from the station. From Fifth Avenue eastward to the lowest point under the river, the grade was to be 1.5% on all lines. Later, during construction, when excavating westward under 33d Street from Fifth Avenue, the surface of the rock was broken through, disclosing quicksand; within the next few days trial drill holes through the tunnel roof at 32d Street and Fifth Avenue showed a thin cover with quicksand above it. The conditions had been indicated in a general way by borings made before construction was begun, but they proved to be rather worse than anticipated. On the topographical map of Manhattan Island, made by General Egbert L. Viele in 1865, is shown a watercourse which had its source near what is now Broadway and 44th Street, flowing thence along the west side and south end of Murray Hill, passing under the present site of the Waldorf-Astoria Hotel, crossing 33d Street at the point where the rock surface was broken through in the tunnel excavation, as above stated, crossing 32d Street at its intersection with Fifth Avenue, where trial drilling showed thin rock cover over the tunnel excavation, passing thence eastward a short distance south of 32d Street, which it recrossed near Third Avenue, and finally discharging into the East River near 34th Street, and a little west of the present First Avenue. The ancient creek apparently followed the course of a valley in the rock, the valley having become filled to a considerable depth with very fine quicksand. This concurrence of depressions in the rock surface

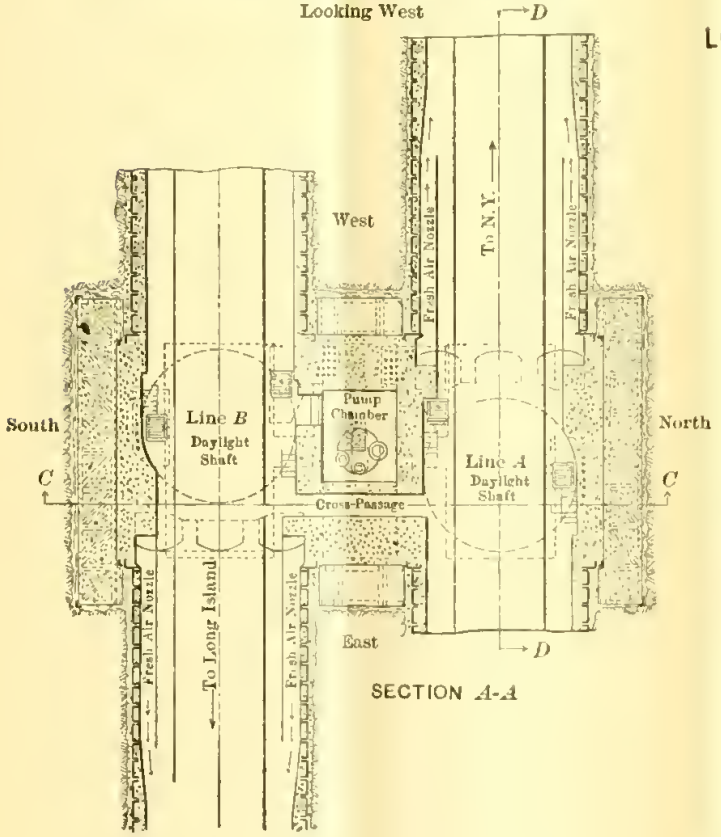


SECTION *C-C*
Looking West

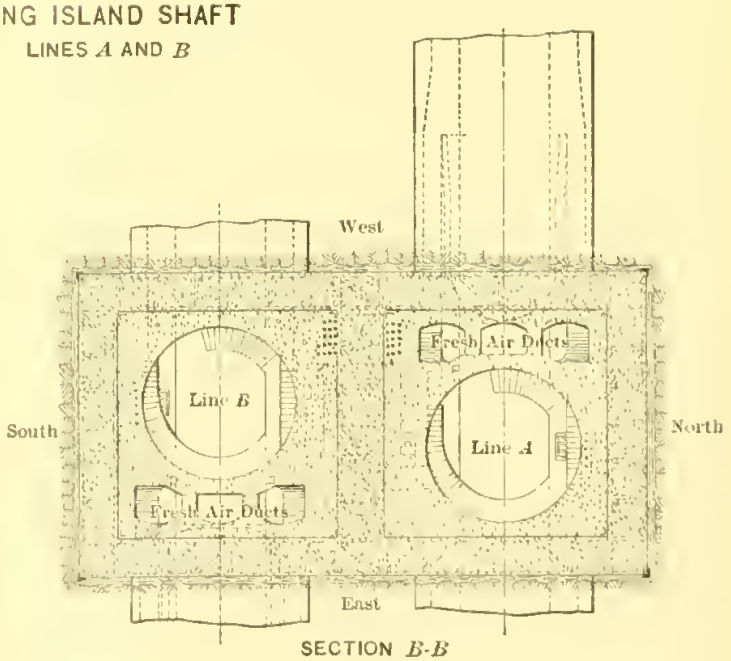


SECTION *D-D*
Looking North

LONG ISLAND SHAFT
LINES *A* AND *B*



SECTION *A-A*



SECTION *B-B*

with the watercourse shown on Viele's map was noted in so many places and the difficulties of construction were so serious at these places, that a section of the map showing the old topography along and adjacent to the station and tunnel lines is reproduced in Plate IX.

The unfavorable conditions developed at Fifth Avenue affected both the construction of the tunnels and the maintenance of adjacent buildings. It would be necessary to construct the tunnels in open cut for a large part of the way westward, causing serious inconvenience to the public; the buildings were mostly of the older class, founded in earth, but there were several modern high buildings with foundations in the same material; some of these had been built since the tunnels were planned. In view of these added risks and the increased cost of construction, the value of the three-track construction was reconsidered, and two important changes were made in the plans. The first of these was to continue the twin tunnel westward to Sixth Avenue in 32d Street, and to a point 180 ft. west of Sixth Avenue in 33d Street; the twin tunnel being 9½ ft. less in height than the three-track tunnel and 9 ft. narrower, the change reduced the difficulties considerably. Where the three-track tunnel was thus eliminated, there was no longer objection to a steeper grade, so that, going eastward from the station, a grade of 0.8% in 33d Street and 0.9% in 32d Street was substituted for the original 0.4% grade. From the west line of Fifth Avenue eastward short sections with descending grades of 0.3% connect with the original 1.5% grade near Madison Avenue. The effect of these two changes—type of tunnel and grade—was to lower the roof of the tunnels at Fifth Avenue about 15 ft., which made it practicable to avoid open cutting east of Sixth Avenue.

A full account of the construction of the cross-town tunnels will be given by the Resident Engineers.

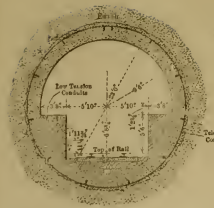
Permanent shafts were made on both sides of the East River, those in Manhattan being located a few feet east of First Avenue, and those in Long Island City being located, one in the so-called Annex Slip, the other in the pier just south of it. The two railroad lines coming from 32d Street in Manhattan, and curving to the left at Second Avenue, are about 34 ft. apart between centers at First Avenue, and it was convenient to make the shaft large enough to cover both lines. Borings had shown that the excavation for the tunnels would break out of the rock about 200 ft. east of First Avenue. It was desirable to

carry the tunnel excavation eastward from the shaft in normal air far enough to permit of building at least 50 ft. of tunnel and installing air-locks, so that compressed air might be available when the rock surface was broken through. The location adopted, and shown on Plate XIII, had the further advantages that the rock surface was several feet above the level of the top of the tunnels, and access to the river for receiving and discharging materials could be had without crossing any street. Similar reasons governed the location of the north shaft for the lines from 33d Street. On the Long Island side of the river there were only two feasible locations meeting these conditions, particularly in respect to a safe thickness of rock above the tunnels, one near the pierhead line, the other just outside the bulkhead line, and for many minor reasons the latter was preferable. The center lines of each pair of tunnels were 37 ft. apart, and each shaft, therefore, was made to cross both lines of a pair, the same as on Manhattan side of the river. It was not expected, however, that the Long Island shafts could be built conveniently or the tunnels begun from them in normal air.

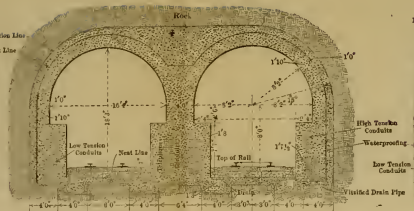
The decision to make the shafts of permanent construction was based not only on the desirability of having access to and egress from the tunnels near the banks of the river for convenience of the workmen or exit for passengers in case of accident, but to facilitate ventilation; these locations divide the entire lengths of tunnels east of the station into three parts, two of which were approximately 4 000 ft. each, and the other about 5 500 ft. The accident risk was believed to be very small, while much weight was given to the feature of facilitating ventilation. Further studies have enhanced the importance attached to ventilation, and it is now intended to provide appliances for mechanical ventilation at all shafts. The plans of the shafts are shown on Plates X and XI. The caissons for the shafts are of structural steel, with double walls, filled between with concrete, including a cross-wall between and parallel to the tunnels. All these structures were fitted for sinking with compressed air, if that should prove necessary.

Although borings had shown that rock would be found at all the shaft sites several feet above the tunnel level, it could not be determined in advance of excavation whether the caissons would have to be sunk to full depth; if sound, unfissured rock were found, the sinking could

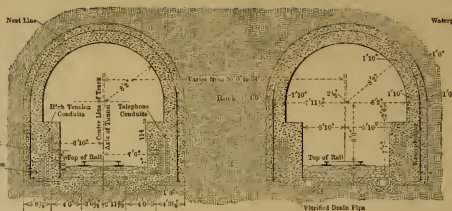
TYPICAL TUNNEL SECTIONS



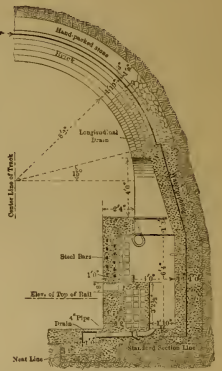
TUBE TUNNEL



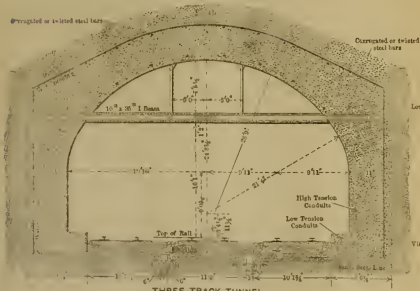
TWIN TUNNEL WITH CONCRETE-DIVIDING WALL



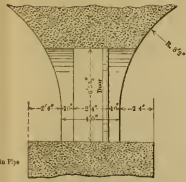
TWIN TUNNEL WITH ROCK-DIVIDING WALL



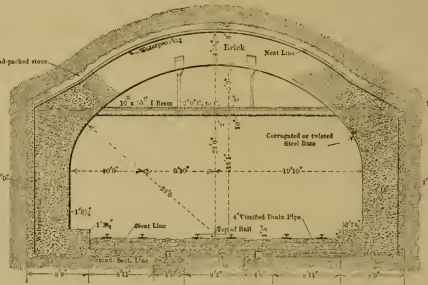
SPLICING CHAMBER
FOR HIGH TENSION CABLES



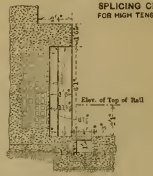
THREE TRACK TUNNEL
CONCRETE ROOF



CROSS PASSAGE



THREE TRACK TUNNEL
BRICK ROOF



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be stopped above the tunnel level; but, if not, the caissons, in any case, would have to be sunk far enough to permit placing a water-tight floor below the tunnels, and the tunnels themselves begun through openings in the side-walls of the caisson; such openings, therefore, closed by removable bulkheads, were provided in all caissons.

As already stated, the grade of 1.5% from Fifth Avenue eastward was fixed with reference to the lowest point of the river bed in order to give the requisite cover over the tunnels at the deepest point of the channel on the west side of the reef, where the river bottom was about 60 ft. below mean high tide for a short distance. On the other hand, as the use of compressed air in building the tunnels was anticipated, an excessive depth below the water surface was to be avoided as far as possible; it was necessary, however, to continue the descending grade some further distance until the tunnels were mostly in rock, so that drainage sumps under the tunnels could be made readily. Eastward from the sumps the tunnels had a rising grade of 0.7% to the established bulkhead line on the Long Island side, giving a cover at the points where the tunnels enter rock, a short distance westward, of about 10 ft. (if the dredging plane should be fixed at some future time at 40 ft. below mean low tide, as may be reasonably anticipated). Eastward from the bulkhead line, Tunnels *A*, *B*, and *D* have ascending grades of about 1.25%, while Tunnel *C* rises at the rate of 1.9% in order to effect a crossing over Tunnel *B* west of the portals. This feature was introduced in order to place the two west-bound tracks together through the Sunnyside Yard, and the heavier grade, being downward with the traffic, was not objectionable.

The arrangement of grades and tracks in the approaches and in Sunnyside Yard would require the introduction of too much detail to be taken up here, but will be dealt with in the paper on the Sunnyside Yard.

It was recognized from the inception of the project that the tunnels under the East River would be the most difficult and expensive section of the East River Division. The borings had shown a great variety of materials to be passed through, embracing quicksand, coarse sand, gravel, boulders, and bed-rock, as well as some clayey materials. (See Plate XIII.) The rock was usually covered by a few feet of sand, gravel, and boulders intermixed, but, in some places, where the rock surface was at some distance below the tunnel grade, the material met in

tunneling was all quicksand; the nearest parallels in work previously done were some of the tunnels under the Thames, particularly the Blackwall tunnel, where open gravel was passed through. Before the plans for the East River tunnels were completed, work had been resumed, after many years' interruption, in the old Hudson River tunnels between 15th Street, Jersey City, and Morton Street, Manhattan, and sand materials were passed through for a short distance. These experiences satisfied nearly all the engineers in any way connected with the work that the shield method was the most suitable for the East River tunnels, and the plans for the work were based on its adoption. (See Plate XII for cross-sections, etc.) Other methods, as stated by General Raymond in the introductory paper, were advocated, particularly caisson constructions and the freezing process, the latter being urged very strongly, and, when proposals were invited, in October, 1903, bidders were informed that alternative methods would be taken into consideration.

Bids were received and opened on December 15th, 1903. Only one bidder proposed to carry out the work on the basis of unit prices, but the prices were so low that the acceptance of the proposal was deemed inadmissible; no bid based on caisson methods was received; several offers were made to perform the work by the shield method, in accordance with the plans, for a percentage of its cost, and one was submitted, on a similar basis, covering the use of the freezing method. The firm of S. Pearson and Son, Limited, of London, England, submitted a proposal for building the tunnels by the shield method, on a modification of the percentage basis, and as this firm had built the Blackwall tunnel within the estimates of cost and was the only bidder having such an experience and record in work in any way similar to the East River tunnels, negotiations were continued between that firm and the railroad company.

The original plans and specifications contemplated that all tunnels between the First Avenue shafts in Manhattan and East Avenue in Long Island City would be shield-driven, and that work would proceed simultaneously eastward from the First Avenue shafts and both eastward and westward from the Long Island City shafts located west of Front Street at the river, requiring twelve shields. When making their proposal, S. Pearson and Son, Limited, suggested that shields might be started from the east end of the work and arrive at the

PLATE XIII.
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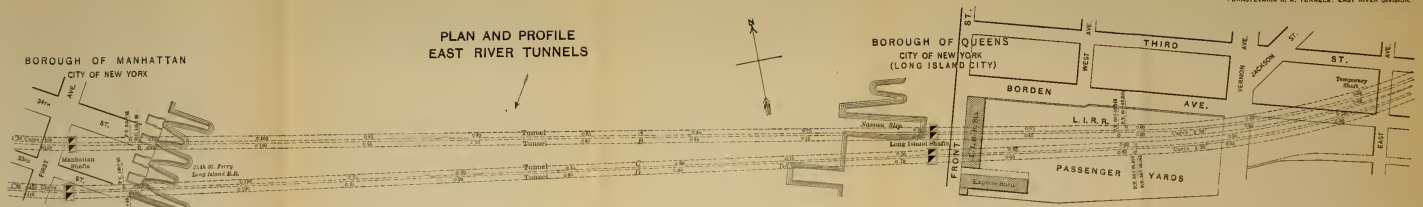
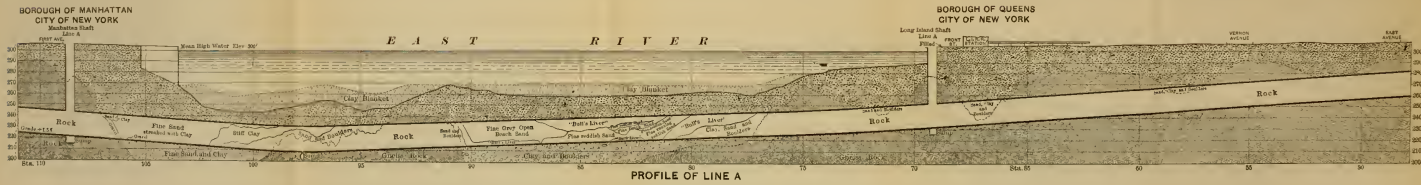
PENNSYLVANIA R. R. TUNNELS: EAST RIVER DIVISION.

PLAN AND PROFILE
EAST RIVER TUNNELS





Front Street shafts as soon as these shafts could be completed, and proposed sinking a temporary shaft transversely across all four lines near the east end of the work just west of East Avenue, from which, within a short time, to drive toward Front Street by the use of shields. The railroad company accepted the suggestion for the additional shaft, although the greater part of the tunnels east of Front Street was built without shields. After several months of negotiation, a contract was entered into on July 7th, 1904, with S. Pearson and Son, Incorporated, a corporation of the State of New York organized by the English firm for the purpose of entering into and carrying out this contract. The main features had been agreed upon, and work had begun about two months before. The contract embraced the permanent shafts in Manhattan and Long Island City, the tunnels between these shafts, and their extension eastward in Long Island City to East Avenue, including in all about 23 600 ft. of single-track tunnels. The contract had novel features, and seemed to be peculiarly suitable for the unknown risks and the unusual magnitude of the work. A fixed amount was named as contractor's profit. If the actual cost of the work when completed, including this sum named as contractor's profit, should be less than a certain estimated amount named in the contract, the contractor should have one-half of the saving. If, on the other hand, the actual cost of the completed work, including the fixed sum for contractor's profit, should exceed the estimated cost named in the contract, the contractor should pay one-half the excess and the railroad company the other half; the contractor's liability was limited, however, to the amount named for profit plus $1 000 000; or, in other words, his maximum money loss would be $1 000 000. Any further excess of cost was to be borne wholly by the railroad company. The management of the work, with some unimportant restrictions, was placed with the contractor; the relations of the engineer, as to plans, inspection, etc., were the same as in ordinary work, and the interest of the contractor to reduce cost was the same in kind as in ordinary work.

On account of the extent of the work embraced in this contract, and the dangerous exposure to compressed air required in most of it, it was divided into three residencies; two of these, including also the cross-town tunnels, have been described; the third, with S. H. Woodard, M. Am. Soc. C. E., as Resident Engineer, embraced all tunnels from the easterly end of the work near East Avenue in Long Island City to

the meeting points under the river and also the permanent shafts in Long Island City. A few months after the execution of the principal contract, the work to be done was extended eastward 107.5 ft., across East Avenue. The extensions of the tunnels were built without cast-iron linings and with an interior cross-section of the same height as the tube tunnels, but somewhat narrower. The work was also extended westward from the First Avenue shafts to include the excavation of top headings in each tunnel for a distance of 100 ft. and an enlargement to full size for 50 ft. The borings having shown that soft earth existed below the grade of the tops of the tunnel under the passenger station building of the Long Island Railroad on the east side of Front Street, and that earth of varying character would be met in places beyond the station building under the railroad tracks in the passenger yard and the street car tracks in Borden Avenue, it had been decided, before proposals were invited, to extend the metal lining eastward to East Avenue, at the east end of the work embraced in the original contract, where the rising tunnel grades approached the surface of the ground so closely that their further extension would be in open cut. In places where the tunnels were wholly in rock, the weight of the cast-iron tunnel lining was reduced 43%; where the surface of the rock was below the top of the tunnel, but above the axis, the reduction of weight was somewhat less, about 25%; notwithstanding these savings, the cost of the tunnels was probably increased by the use of the cast-iron lining; on the other hand, when passing through bad ground, a section of tunnel could be made absolutely safe more quickly by erecting the lining as soon as a length of a few feet of tunnel was ready; under a crowded passenger yard, this feature had great value.

The execution of the work under this contract will be described fully by the Resident Engineers.

The plant assembled by the contractors is believed to be the most extensive ever placed on a single piece of work, and will be described in detail by their Managing Engineer, Henry Japp, M. Am. Soc. C. E.

For convenience in receiving materials to be used in construction, and to facilitate the disposal of excavated materials, one pier was leased on the east side of the Hudson River, two on the west side of the East River and three on the east side. Excavated materials from the station, the cross-town tunnels, and the river tunnels, were placed on barges furnished by Mr. Henry Steers under several contracts

PLATE XIV.
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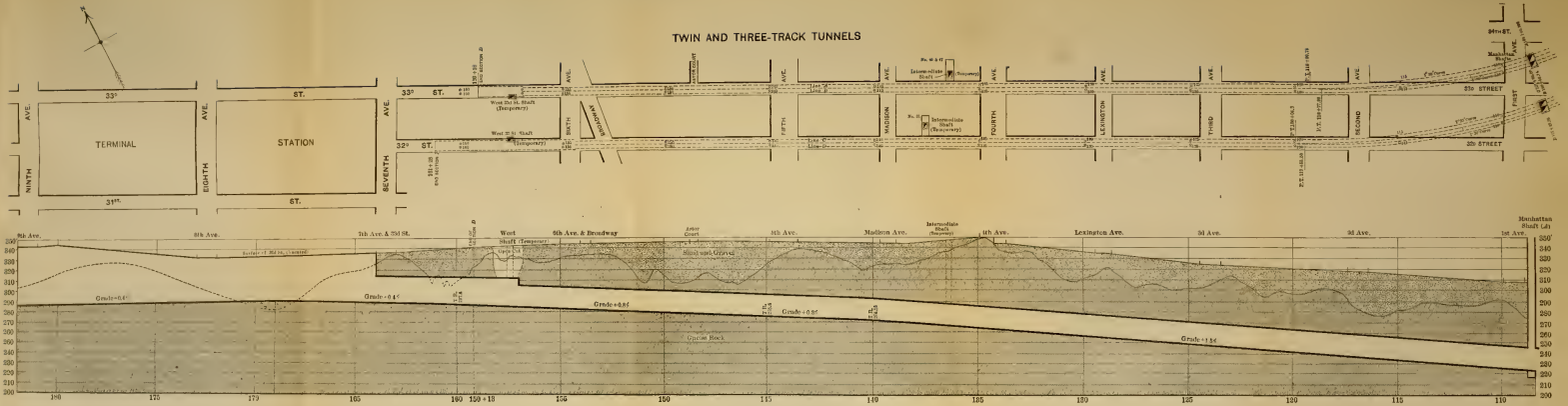
NOBLE ON
PENNSYLVANIA R. R. TUNNELS: EAST RIVER DIVISION.



embracing also the disposal of the materials. In the earlier part of the work, they were used as fill in the freight terminal of the Pennsylvania Railroad at Greenville on the west side of the Upper Bay; when the fill at this place was completed, the materials were sent to the tunnel company's yard on the Passaic, at Harrison, N. J., and a small part to the embankment in the Meadows Division. On account of the occasional closing of the Passaic by ice, this involved the possibility of, and to some extent resulted in, interruptions to the work of excavation. The contract for the cross-town tunnels carried an option in favor of the company to require the contractor for those tunnels to dispose of materials at a stated price, and in the latter part of 1907, when the excavation in these tunnels was being pushed rapidly, the railroad company, unwilling to incur the responsibility for delays during the winter, availed itself of this option. The disposal of materials was an important part of the work, and will be dealt with more fully by the Resident Engineers.

At the time the contract was made with S. Pearson and Son, Incorporated, it had not been determined whether mechanical ventilation would be provided for the tunnels, and therefore the contract with that firm did not include the final concrete lining at the shafts, above the inverts of the tunnels. After the adoption of plans for mechanical ventilation, in the latter part of 1908, the plans for lining the shafts with concrete, including flues for conducting air to the tunnels, and stairways for ingress and egress, were completed, and the work was placed under contract; it will be described in detail by F. M. Green, Assoc. M. Am. Soc. C. E.

At the east end of the work under the Pearson contract, the rising grade of the tunnels brought them so near the surface of the ground that their extension eastward could be carried out more readily in open cut than by tunneling. The locations of the portals could be varied somewhat, and they were built on rock which was found in rather narrow ridges at convenient places. Tunnels *B* and *D* have a common portal; Tunnels *A* and *C* have separate ones, the portal for Tunnel *C* being located about 800 ft. west of the others as a result of its crossing over Tunnel *B*, as already explained. Eastward from the portals, the track system expands, in order to provide connections with the tracks of the Long Island Railroad to and from Long Island City, with the New York Connecting Railroad and New England lines, and with the

storage and cleaning yard known as the Sunnyside Yard extending to the west side of Woodside Avenue, 2¾ miles east of the East River. (Plate XV.) The yard and approaches are designed to avoid grade crossings by opposing trains. The various general features of the yard and tunnel approaches, bridge crossings, and street closings, have been described in sufficient detail by General Raymond in the introductory paper.

For convenience in placing the work under contract, a line was drawn 10 ft. west of Thomson Avenue, dividing the work east of that embraced in the Pearson contract into two parts. The work west of the line was placed under the immediate direction of George C. Clarke, M. Am. Soc. C. E., as Resident Engineer, with Naughton Company and Arthur McMullen, Contractors; Mr. Louis H. Barker was Resident Engineer of the part east of the dividing line, with the Degnon Realty and Terminal Improvement Company as the principal contractors. The substructures of the several bridges in or across the yard were included in these contracts, but the superstructures were carried out by various bridge companies, and other minor features were executed by other contractors. More complete descriptions of the plans and of the execution of the work will be given by the Resident Engineers.

PLATE XV.
TRANS. AM. SOC. CIV. ENGRS.
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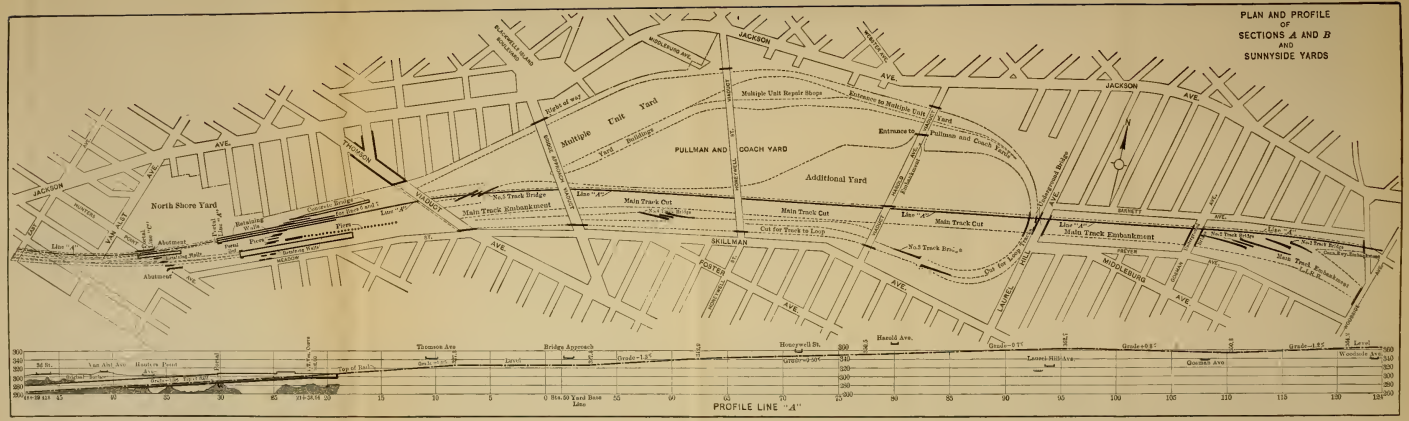
NOBLE ON
PENNSYLVANIA R. R. TUNNELS: EAST RIVER DIVISION.



AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1153

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. MEADOWS DIVISION AND HARRISON TRANSFER YARD.*

By E. B. Temple, M. Am. Soc. C. E.

The New York Tunnel Extension of the Pennsylvania Railroad diverges from the New York Division in the Town of Harrison, N. J., and, ascending on a 0.5% grade, crosses over the tracks of the New York Division and the main line of the Delaware, Lackawanna and Western Railroad. Thence it continues, with light undulating grades, across the Hackensack Meadows to a point just east of the Northern Railroad of New Jersey and the New York, Susquehanna and Western Railroad, where it descends to the tunnels under Bergen Hill and the North River. (Plate XVI.)

That portion of the line lying west of the portals of the Bergen Hill Tunnels has been divided into two sections: First, the most westerly, known as the Harrison Transfer Station and Yard (Plate XVII), which is located on the southern side of the New York Division, Pennsylvania Railroad, and extends from the connection with the New York Division tracks at grade up to the point of crossing the same, where the Pennsylvania Tunnel and Terminal Railroad has its beginning; second, the Meadows Division of the Pennsylvania Tunnel and Terminal Railroad, which is a double-track railroad, 5.08 miles long, extending from a point just west of the bridge over the New York Division to a point 300 ft. west of the western portals of the Bergen Hill Tunnels.

* Presented at the meeting of June 1st, 1910.

Harrison Transfer Station and Yard.—The necessities for the Harrison improvements are two-fold: First, as a place to change motive power from steam to electric, and *vice versa;* second, as a transfer for passengers from trains destined to the new Station at Seventh Avenue and 33d Street, New York City, to steam or rapid transit trains destined to the present Jersey City Station, or to the lower part of New York City *via* the Hudson and Manhattan Tunnels, and *vice versa.*

All steam trains from Philadelphia, the South, and the West, from New Jersey seashore resorts, and local trains on the New York Division bound for the new Pennsylvania Station, will change their motive power from steam to electric engines at the Harrison Transfer Station. Likewise, all trains from the Tunnel Line will change from electric to steam motive power there, and passengers coming from Jersey City and the southern section of New York City can take through trains at the Harrison Transfer platforms. It is estimated that the time required to make this change of motive power, or to transfer passengers, will not exceed 3½ min.

The plan at Harrison provides at present for two platforms, each 1 100 ft. long and 28 ft. wide, and having ample shelters and waiting rooms, connected by a 12-ft. tunnel under the tracks, provision being made for two additional platforms when necessity requires their construction. The platforms are supported on walls of reinforced concrete, with an overhang to provide a refuge for employees from passing trains. The concrete walls are supported on wooden piles, prevented from spreading by ¾-in. tie-rods at 10-ft. intervals, and embedded in concrete under the paving of the platform. As the elevation of the top of the platform is +21.83, and the top of the piles is +14.54 above mean tide, the piles will, of course, decay; but, as the embankment has been completed for some time and is well packed and settled, the concrete being deposited directly on the embankment, very little trouble from settlement is anticipated when the piles decay. The surface of the platforms, with the exception of the edges, is to be of brick, on a concrete base; and, if settlement occurs, the bricks can be taken up and re-surfaced. The tops of the platforms are 3 ft. 10 in. above the top of the rail and on a level with the floors of the cars, so that passengers may enter or leave trains without using steps, as all cars which will enter the Pennsylvania Station, New York City, are to be provided with vestibules having trap-doors in the floor to give access

PLATE XVI.
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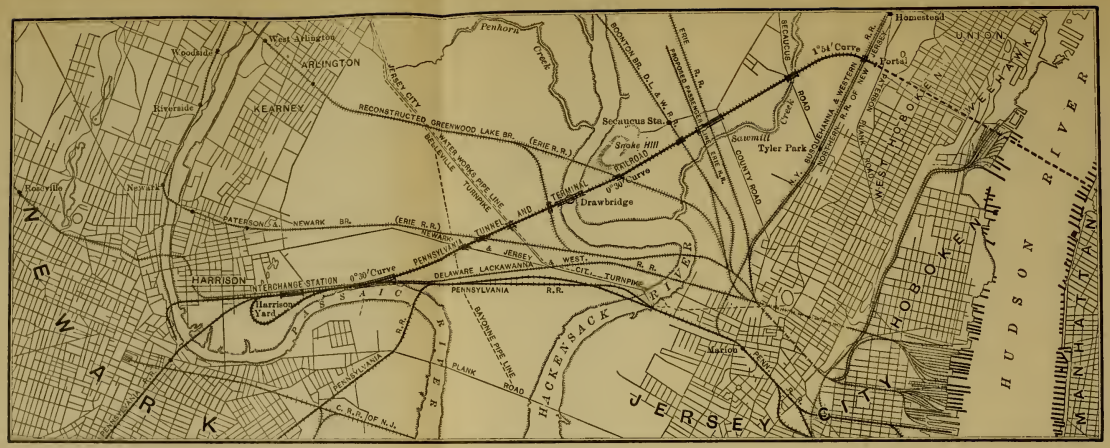
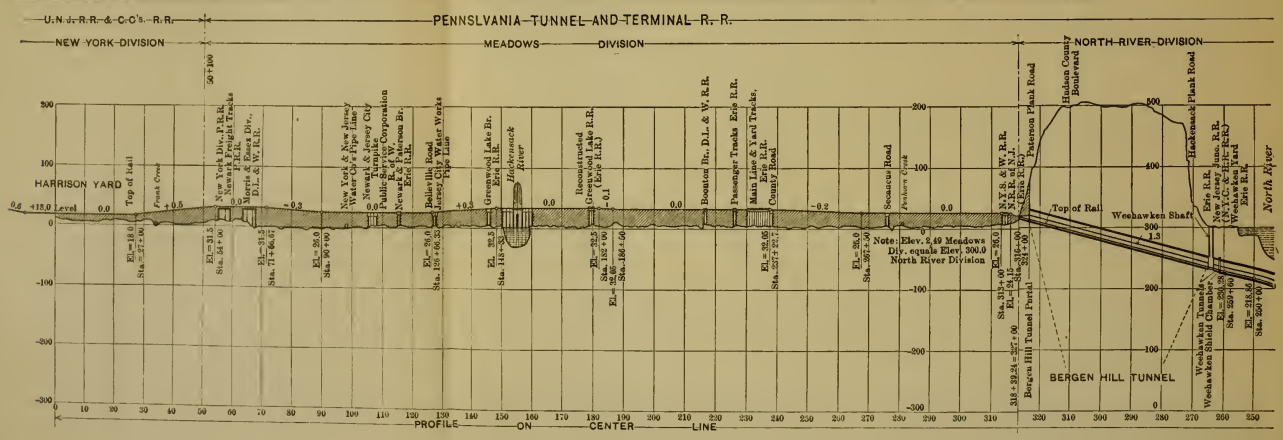
TEMPLE ON
PENN. R. R. TUNNELS:
MEADOWS DIV. AND HARRISON YARD.





to either high or low platforms. Details of the platforms are shown on Plates XVIII and XIX.

As planned at present, there will be four main running tracks, one adjacent to each side of the two platforms, providing standing room for four of the longest trains, two in each direction, or double the number of trains of ordinary length, so that passengers having to tranfer from a train destined to the Pennsylvania Station at 33d Street to a train destined for the Jersey City Station or the Hudson and Manhattan Tunnels will merely cross the platform. Between the two interior main tracks are two shifting tracks, so that between the platforms there will be two passenger tracks on which trains will stop to change motive power and transfer passengers, and two shifting tracks for rapid despatching of the empty engines and motors, each of the four tracks being 15 ft. from center to center to allow for uncoupling and inspection of cars.

An efficient system of connections and cross-overs is provided for all tracks, and there is ample storage capacity for 10 steam engines at the western end of the platforms and 20 electric motors at the eastern end, both of which are conveniently located for quick movement, with provision for additional storage tracks, if required. Steam engines, upon being disconnected, can be quickly sent to the main engine storage yard, and by the use of a loop track no turntable is required. The main engine storage yard is located south of the running tracks adjoining the bulkhead along the Passaic River, where provision is made for the storage of 20 engines. There are two 50 000-gal. water tanks, an ash-pit, inspection-pit, work-pit, sand-hopper, and the necessary buildings. Water is brought from the city water main in the Meadows Yard, on the New York Division, about 8 200 ft. eastward from the center of this yard.

It was at first planned to locate a power-house and car and engine repair shops in the yard, but as the ultimate extent of the electrification of the New York Division cannot now be determined, the facilities in the large power-house in Long Island City, and in the shop and round-house in the Meadows Yard of the New York Division, were increased to provide for the power and repairs necessary for the next few years. In order to reach the Meadows shops and round-house without interfering with the present passenger and freight tracks, it was necessary to build track connections with the Meadows Yard. Twelve

stalls of the existing round-house were extended to accommodate the motive power; a large transfer table and pit were increased in size, and an additional ash-pit and engine storage tracks were constructed.

Any extensive repairs to the electric engines will be made for the present in the Jamaica Shops, Long Island; and the large shops at Trenton, on the New York Division, as well as the Meadows Shops, will be available for repairs to the steam locomotives. There is ample room at Harrison, and plans have been prepared providing for storage and light repair of cars, locomotives, electric motors, and rapid transit trains, if the future demands require such construction at this place.

The rapid transit line will extend from Park Place, Newark, to Harrison, and thence over the present line of the Pennsylvania Railroad, which will be electrified, to a junction with the Hudson and Manhattan Railroad Company's tunnel tracks at Prior Street, Jersey City. It will be constructed and owned by the Pennsylvania Railroad Company. A joint and frequent through service will be conducted by both companies between Park Place, Newark, and the terminal of the Hudson and Manhattan Railroad, in New York City, by the use of multiple-unit trains similar to those now being operated in the Hudson and Manhattan tunnels. These trains will pick up and discharge Pennsylvania Railroad passengers at the Harrison Transfer Station, so that all passengers bound for lower New York City, who desire to use the tunnel service, will make the change at Harrison instead of at Jersey City as at present. Provision is made for two additional platforms, each 1 100 ft. long, to accommodate the rapid transit trains when the present platforms prove inadequate. The existing passenger tracks between the Harrison Transfer Yard and Summit Avenue, Jersey City, where a new local passenger station will be constructed, will be used jointly by steam and electric trains.

The embankment for the Harrison Yard was made, under contract dated July 21st, 1906, with Henry Steers, Incorporated, of New York City, of cellar earth from New York City, and with rock and earth excavated from the Pennsylvania Station and cross-town tunnels. It was necessary to construct 1 000 ft. of stone and crib bulkhead along the bank of the Passaic River. The plan of the yard was prepared by a committee of operating, electrical, and engineering officers, consisting of Mr. F. L. Sheppard, General Superintendent, New Jersey Division, Pennsylvania Railroad Company; George Gibbs, M. Am.

PLATE XVII.
TRANS. AM. SOC. CIV. ENGRS.
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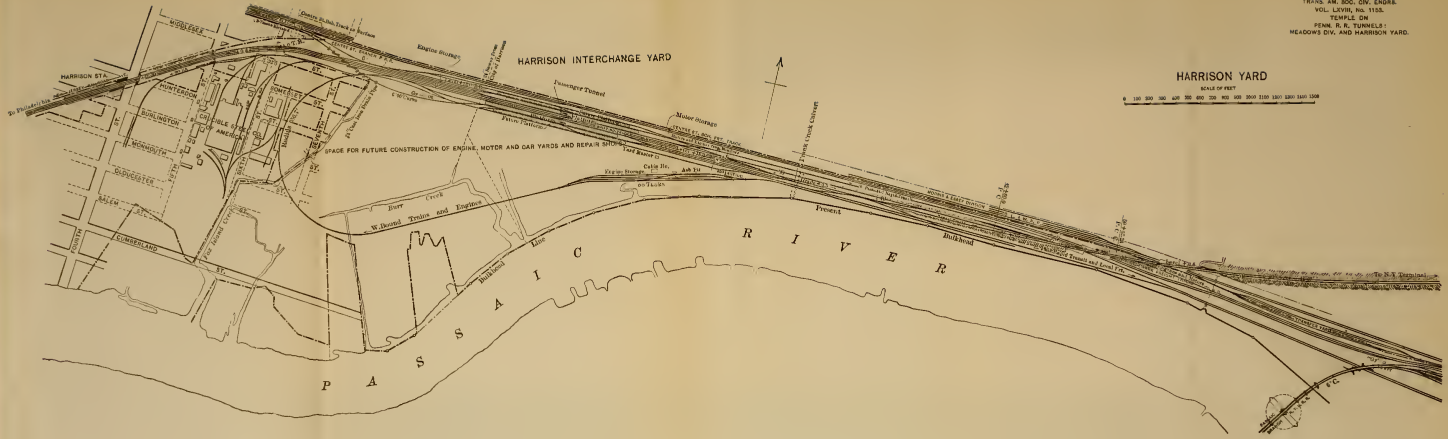
TEMPLE ON
PENN. R. R. TUNNELS:
MEADOWS DIV. AND HARRISON YARD.



Soc. C. E., Chief Engineer, Electric Traction and Terminal Station Construction, Pennsylvania Tunnel and Terminal Railroad Company; Mr. J. A. McCrea, General Superintendent, Long Island Railroad Company; Mr. C. S. Krick, Superintendent, Pennsylvania Tunnel and Terminal Railroad Company; Mr. A. M. Parker, then Principal Assistant Engineer, New Jersey Division, Pennsylvania Railroad Company, now Superintendent, Hudson Division; and approved by Mr. A. C. Shand, Chief Engineer, Pennsylvania Railroad Company, and Chief Engineer, Meadows Division, Pennsylvania Tunnel and Terminal Railroad Company.

Meadows Division, Pennsylvania Tunnel and Terminal Railroad.— The two main tracks ascending through the Harrison Yard continue on an embankment to a point 500 ft. west of the west abutment of the bridge over the New York Division tracks, which is the point of beginning of the Pennsylvania Tunnel and Terminal Railroad. From this point the line extends in a general northeasterly direction, crossing the Hackensack River, skirting the base of Snake Hill, and thence to the approach cut to Bergen Hill Tunnels. The embankment varies in height from 25 to 30 ft. above the surface of the meadows.

In this Division the following bridges were necessary:

Pennsylvania Railroad, New York Division, Passenger and Newark Freight Tracks;
Delaware, Lackawanna and Western Railroad, Morris and Essex Division;
Newark and Jersey City Turnpike;
Public Service Corporation Right of Way;
Erie Railroad, Newark and Paterson Branch;
Belleville Road, and Jersey City Water Company's Pipe Line;
Greenwood Lake Railroad (Erie Railroad), Arlington Branch;
Hackensack River;
Greenwood Lake Railroad (Erie Railroad), Reconstructed Line;
Delaware, Lackawanna and Western Railroad, Boonton Branch;
Erie Railroad, Passenger Tracks;
Bridge of 11 spans over proposed yard tracks, Erie Railroad;
County Road;
Secaucus Road;
New York, Susquehanna and Western Railroad;
Northern Railroad of New Jersey.

The alignment for this distance consists of 3.57 miles of tangent and three curves, two of which are 0° 30′ each, one of the latter being at the western end of the Division, and the other adjoining Snake Hill; the third is a regular curve of 1° 54′ on the east-bound track, and a compound curve with a maximum of 2° on the west-bound track, the variation being due to the track spacing of 37 ft. from center to center in the Bergen Hill Tunnels, while on the Meadows Division it is 13 ft. from center to center.

The profile was adopted to give 18 ft. of clearance from the under side of the bridges to the top of the rail of the Erie Railroad branches, 21 ft. to the top of the rail of its main line, 19 ft. to the top of the rail of the Delaware, Lackawanna and Western Railroad, and a clearance of 24 ft. above high water in the Hackensack River. With the exception of that portion of the line adjoining the Bergen Hill Tunnels, where it was necessary to continue the 1.3% grade up to the bridge over the Northern Railroad of New Jersey, and the east-bound ascending grade of 0.5% from the Harrison platforms to the bridge over the New York Division tracks, the grades do not exceed 0.3 per cent.

When the construction of the embankment was commenced, it was expected that there would be considerable trouble by settlement due to the displacement of the soft material underlying the surface of the meadows to a depth of from 10 to 15 ft.; but, with the exception of the trouble the contractors had in maintaining their temporary trestles, the embankment as completed has settled very little. The section east of the Hackensack River was made, in great part, of rock excavated from a borrow-pit in the Town of Secaucus, north of the eastern end of the Division. The embankment was built under two contracts, one for the work east of the crossing of the Boonton Branch of the Delaware, Lackawanna and Western Railroad, under contract dated January 15th, 1907, with H. S. Kerbaugh, Incorporated, the material being taken from the borrow-pit in narrow-gauge cars and dumped from a strong pile trestle along the total length of the section, the same being completed in 19 months; the other for the embankment west of the Boonton Branch, Delaware, Lackawanna and Western Railroad, under contract dated April 10th, 1906, with Henry Steers, Incorporated, of New York City, the material, consisting partly of cellar earth, and partly of rock and earth excavated from other sec-

PLATE XVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1153.
TEMPLE ON
PENN. R. R. TUNNELS:
MEADOWS DIV. AND HARRISON YARD.

DETAILS OF SHELTERS AND PLATFORMS HARRISON TRANSFER STATION HARRISON, N.J.

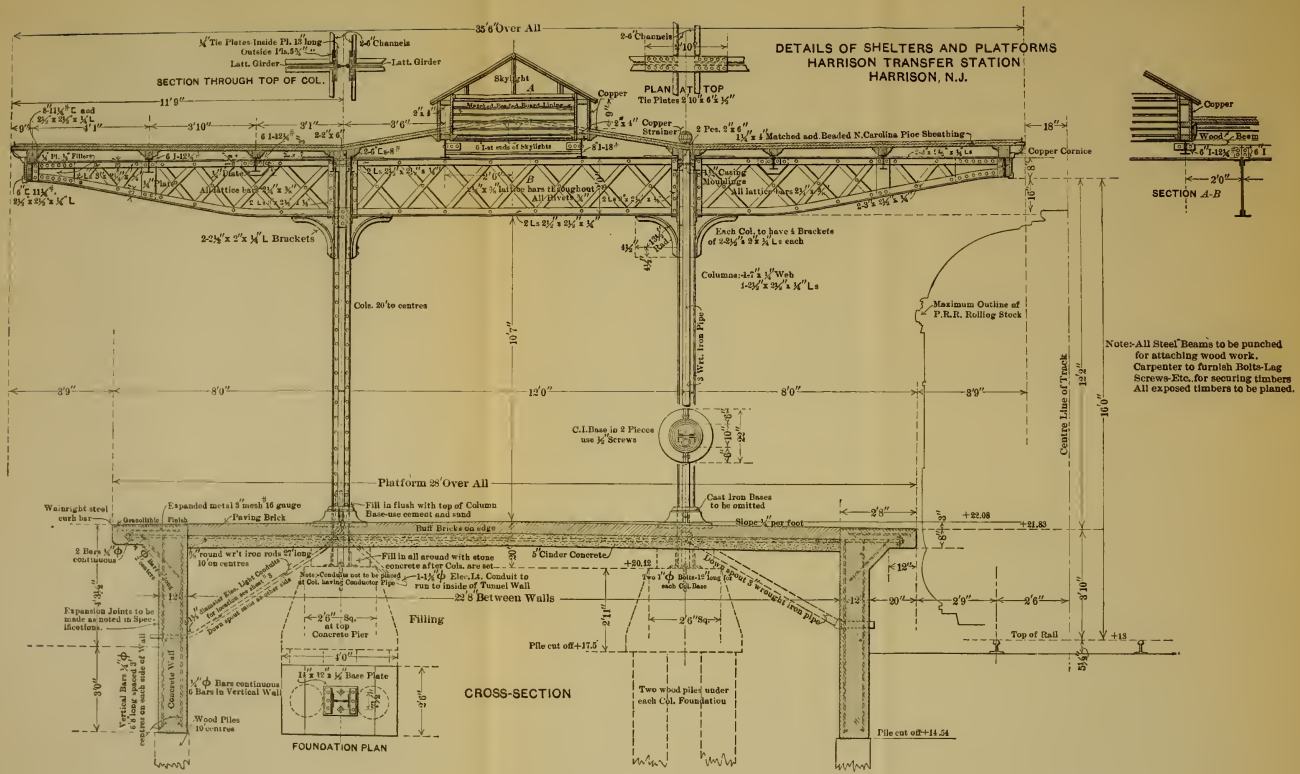


PLATE XIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1153.
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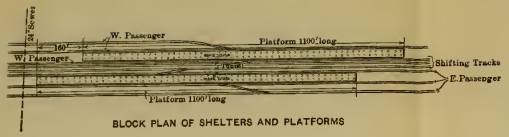
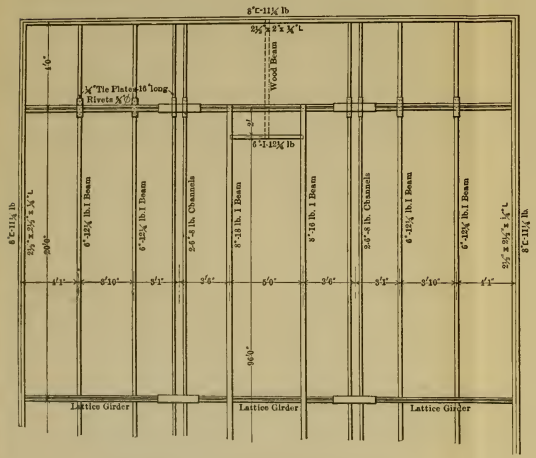
MEADOWS DIV. AND HARRISON YARD.

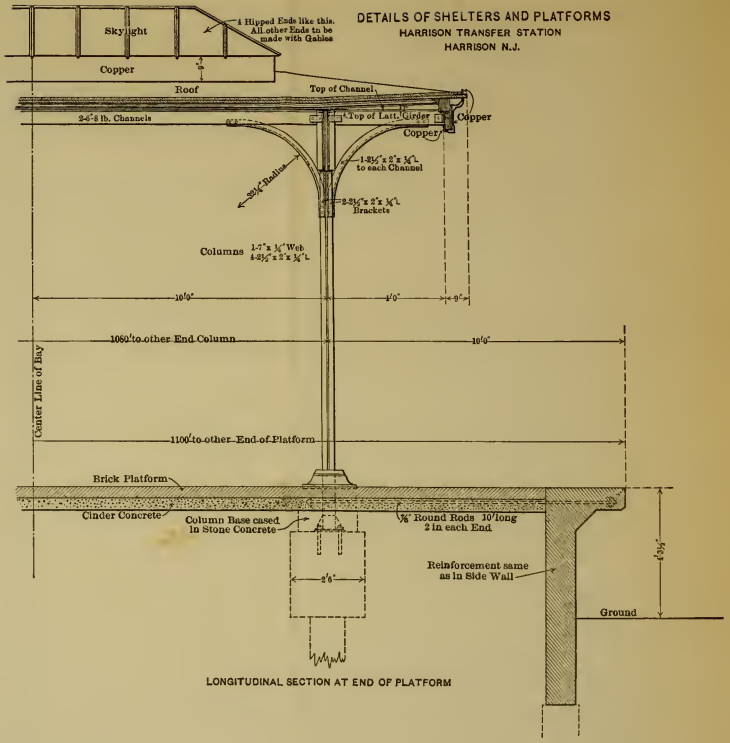


BLOCK PLAN OF SHELTERS AND PLATFORMS



PLAN OF STEEL IN END BAY—INTERMEDIATE BAYS SIMILAR

DETAILS OF SHELTERS AND PLATFORMS
HARRISON TRANSFER STATION
HARRISON N.J.



LONGITUDINAL SECTION AT END OF PLATFORM

tions of the Pennsylvania Tunnel and Terminal Railroad, being brought on scows up the Hackensack and Passaic Rivers from New York City. The material was handled expeditiously from the scows by orange-peel buckets operated from the shore, deposited in standard-gauge dump-cars, and transported by locomotives at one time used on the elevated railroads in New York City. No excavation whatever was required on the Meadows Division or in the Harrison Yard.

The substructures for all the bridges, except the Hackensack River Draw-bridge, are of concrete, without reinforcement, heavy enough to withstand the ordinary earth pressure for the exposed height. With the exception of three bridges, foundations were built on clay and sand; these three, on account of excessive depth of soft material, were built on piles. In some cases loose stone was deposited back of the foundations for a width of 10 or 12 ft. after the mud had been removed. This precaution has prevented trouble due to the thrust of the high embankments on the saturated material. Masonry for all these bridges was constructed under contract dated August 21st, 1905, with McMullen and McDermott, of New York City. The superstructure consisted principally of half-through girders, floor of I-beams, filled solid with concrete, on top of which were placed five layers of Hydrex felt, and water-proofing compound, protected by a layer of sand and grouted brick from the stone ballast.

The bridges over the New York Division passenger and Newark freight tracks of the Pennsylvania Railroad, and the main-line tracks of the Delaware, Lackawanna and Western Railroad, at the west end of the Meadows Division, are separated by 300 ft. of embankment. The skew angle is 9°, the total length of each bridge being about 450 ft. The floors consist of I-beams embedded in concrete.

The Hackensack River Draw-bridge consists of six spans of deck plate girders, each 110 ft. long, and a draw-span 300 ft. long, operated by two 70-h.p. electric motors. The masonry was constructed under contract dated August 25th, 1905, with the Drake and Stratton Company, of Philadelphia; and the steelwork was furnished and erected by the Pennsylvania Steel Company, of Steelton, Pa. An important and interesting feature of the draw-bridge is the lift rail, and new rail-locking device. Mitered rails are used, with sufficient opening between the ends to prevent binding at times of expansion. It was deemed advisable that the mitered joint should occur on the abutment,

or fixed span, instead of at the opening at the end of the draw. The lift rail, therefore, was a necessity; and the design, as shown on Plate XX, was perfected. It consists of lift-rails, 8 ft. 4 in. long, moving vertically 8 in. at the free end, reinforced on both sides by sliding steel castings, which are lifted with the rail; when the latter is dropped in place, the wedges on the castings engage at the abutment and heel joints and at one intermediate point in dove-tailed wedge seats, insuring tight contact with the rail, and absolute fastening to the deck of the bridge. The objection to the ordinary lift-rail, which in lowering must make its own joint by seating in tight boxes, has been that any slight deviation from a true line would prevent the rail from seating itself properly. This objection has been entirely overcome in this design, by allowing liberal clearance on all seats, and securing rigidity by the sliding bars and wedges which are connected with the interlocking system, so that it is impossible for a clear signal to be given unless the lift-rails and wedges are in their proper positions. This device has been operated successfully on the New York and Long Branch Railroad bridge over Raritan Bay for the last 18 months.

Each of the two main tracks on the Meadows Division, and all the main tracks in the Harrison Transfer Yard, are of standard construction, with Pennsylvania Section, 1909, 100-lb., open-hearth steel rails, and stone ballast. Every fifth tie is made 9 ft. 5 in. long, to carry the third rail for the electric current, and all joints of the running rails are bonded for the same purpose. Track-laying on the Meadows, and in Harrison Transfer Yard, has been done under contract dated April 26th, 1909, with Henry Steers, Incorporated, of New York City.

Samuel Rea, M. Am. Soc. C. E., Second Vice-President, Pennsylvania Railroad Company, is the executive officer under whose direction the work has been carried on. Mr. William H. Brown, Chief Engineer, Pennsylvania Railroad Company, and Chief Engineer of the Meadows Division, also a Member of the Board of Consulting Engineers for the tunnel extension, until his retirement by age limit on February 28th, 1906, located and started the construction of the line from Harrison to the western portals of the Bergen Hill Tunnels, which latter point was the westernmost limit of authority of the Board of Consulting Engineers. Mr. A. C. Shand succeeded Mr. Brown as Chief Engineer of the Pennsylvania Railroad Company, and as Chief

FIG. 1.—LIFT RAIL AND LOCKING DEVICE, DRAW PARTLY OPEN.

FIG. 2.—LIFT RAIL AND LOCKING DEVICE, DRAW CLOSED.

Engineer of the Meadows Division, with the writer, who was Assistant Chief Engineer of the Pennsylvania Railroad Company, and had been closely associated with Mr. Brown at the time of the location of the line and its earlier period of construction. H. R. Leonard, M. Am. Soc. C. E., Engineer of Bridges and Buildings, Pennsylvania Railroad Company, designed the Hackensack River Bridge, the superstructures of the other bridges, and the rail-locking device on the Hackensack River Draw-bridge. The surveys and construction of the Meadows Divison and of the Harrison Transfer Yard have been in charge of Mr. William C. Bowles, Engineer of Construction.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1154

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE BERGEN HILL TUNNELS.*

By F. Lavis, M. Am. Soc. C. E.

Location.—That section of the Pennsylvania Railroad's New York Tunnels lying west of the Hudson River is designated Section "K," and the tunnels are generally spoken of as the Bergen Hill Tunnels. Bergen Hill is a trap dike (diabase) forming the lower extension of the Hudson River Palisades.

There are two parallel single-track tunnels, cross-sections of which are shown on Plate VIII of the paper by Charles M. Jacobs, M. Am. Soc. C. E. The center line is a tangent, and nearly on the line of 32d Street, New York City, produced, its course being N. 50° 30′ W. The elevation of the top of the rail at the Weehawken Shaft (a view of which is shown by Fig. 2, Plate XXII), on the west bank of the Hudson River, is about 64 ft. below mean high water; and at the Western Portal, or Hackensack end, the rail is about 17 ft. above; the grade throughout is 1.3%, ascending from east to west. The length of each tunnel between the portals is 5 920 ft.

A general plan and profile of these tunnels is shown on Plate I of the paper by Charles W. Raymond, M. Am. Soc. C. E. At

*Presented at the meeting of April 6th, 1910.

Fig. 1.

Fig. 2.

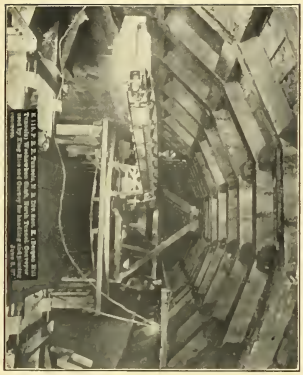


Fig. 3.

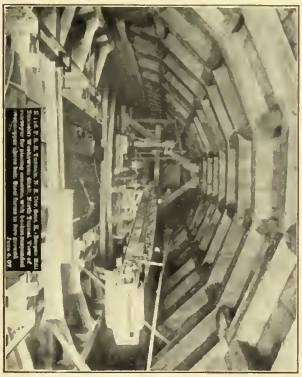


Fig. 4.

a No. 34 slugger drill, with air at 90 lb. pressure, was almost 10 hours. The specific gravity of this rock is not as high as that of some other specimens of trap tested, which were much more easily drilled. This rock was very blocky, causing the drills to bind and stick badly, and, when being shoveled back from the heading, as it fell it sounded very much as though it were broken glass.

The remainder of the trap varied from this, through several changes of texture and color, due to different amounts of quartz and feldspar, to a very coarse-grained rock, closely resembling granite of a light color, though quite hard. The speed of drilling the normal trap in the heading was approximately 20 to 25 min. per ft., as compared with the 60 min. per ft. noted above, the larger amounts of quartz and feldspar accounting for the greater brittleness and consequently the easier drilling qualities of the rock. The normal trap in these tunnels has a specific gravity varying from 2.85 to 3.04, and weighs from 179 to 190 lb. per cu. ft.

The temperature of the tunnels, at points 1 000 ft. from the portals at both ends, remained nearly stationary, and approximately between 50° in winter and 60° in summer, up to the time the headings were holed through, being practically unaffected by daily changes in the temperature outside. At the western end, after the connection with the Central Shaft headings was made, there was almost always a current of air from the portal to the shaft, and ascending through the latter. This tended to make the temperature in this part of the tunnel correspond more nearly with the outside temperature; in fact, the variation was seldom more than 5° Fahr.

Timbering.—These tunnels have been excavated entirely by the center top heading method, almost invariably used in the United States. Timbering, where required, was of the usual segmental form with outside lagging, as shown in several of the photographs. In a few places it was necessary to hold the ground as the work progressed, and, in such cases, crown bars were used in the headings.

There was some little trouble at the Western Portal, where the top of the rock was very near the roof of the tunnel, as shown by Fig. 1, Plate XXI. A side heading was driven at the level of the springing line until a point was reached where the roof was self-supporting, and the timbering was brought out to the face of the portal from that point.

FIG. 1.

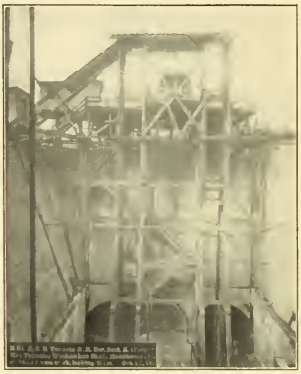


FIG. 2.

FIG. 3.—ROUND HOLES IN CONCRETE FORMS.

FIG. 4.—ROUND HOLES IN CONCRETE FORMS COMPLETED.

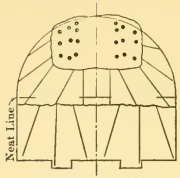
Drilling.—Where no timbering was required, several different methods were used in drilling and excavating the solid rock, though in all cases a center top heading was driven. The four diagrams, Figs. 1, 2, 3, and 4, give typical examples of these methods and show, in the order of their numbers, the general tendency of the development from a small heading kept some distance ahead of the bench, to a large heading with the bench kept close to it. The notes on each diagram give the general details of the quantity of drilling and powder used, methods of blasting, etc., and on the progress profile, Fig. 6, is indicated those portions of the tunnels in which each method was used.

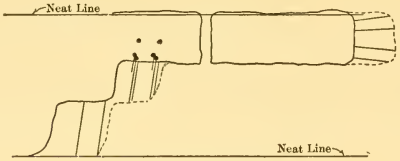
All the drills used throughout the work by Mr. Bradley were Rand No. 34 sluggers, with $3\frac{5}{8}$-in. cylinders, and the steel was that known as the "Black Diamond Brand," $1\frac{3}{8}$-in., octagon. It was used in 2, 4, 6, 8, 10, and 12-ft. lengths; toward the end of the work it was proposed to use 14-ft. lengths, but owing to some delay in delivery this length was never obtained. The starters, 18 to 24 in. long, were sharpened to $2\frac{3}{4}$ to 3-in. gauge, which was generally held up to depths of 6 ft.; then the gauge gradually decreased until it was $1\frac{3}{4}$ to $2\frac{1}{4}$ in. at the bottom of a 12-ft. hole. Frequently, as many as three or four starters were used in starting a hole, and generally two sharpenings were required for each 2 ft. drilled, after the first 6 ft. It is estimated that about $\frac{1}{4}$ in. of steel was used for each sharpening, and that there was an average of one sharpening for every foot drilled.

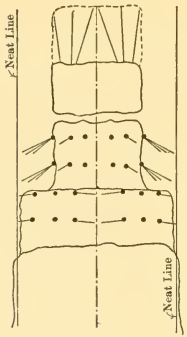
The total quantity of steel used up, lost, or scrapped on the whole work was almost exactly 1 ft. for each 10 cu. yd. excavated, equal to $1\frac{1}{4}$ in. of steel per yard, distributed approximately as follows:

Sharpening	$\frac{3}{4}$ to $\frac{7}{8}$ in.
Other losses	$\frac{1}{2}$ to $\frac{3}{8}$ "
Total	$1\frac{1}{4}$ in. per cu. yd.

An "Ajax" drill sharpener was used, and proved very satisfactory. Rubber and cotton hose, covered with woven marlin, was used for the bench (3 in. inside diameter, in 50-ft. lengths), for drills (1 in. in diameter, in 25-ft. lengths), and for steam shovels ($2\frac{1}{2}$ in. in diameter, in 50-ft. lengths). Hose coverings of wound marlin, and of woven marlin with spiral steel wire covering were tried, but were not satisfactory, owing to the unwinding of the marlin and the bending of the steel covering.





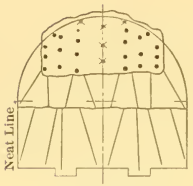


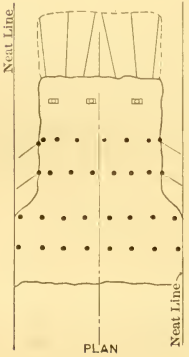
Drilling Method No.1: Small heading, 60 to 80 ft. long. Two columns used in heading, with two drills on each. Drills on sub-bench and main bench mounted on tripods.

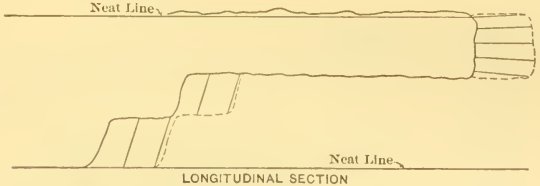
	Per Round				Per Cubic Yard		Per Linear Foot of Tunnel		
	Total Depth Drilled	No. of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No. of Feet Drilled	Pounds of Dynamite
Heading	140-155	18-21.6	93-131	5-6	8-9	5-6	3.6	29.-32	18-22
Bench	110-120	53-60	76-97	3½-4	2	1.4-1.6	15.4	30.-31	21.5-24.6
						Total	19	59.-63	39.5-46.6
						Per cubic yard, whole tunnel section		3 to 33	2.1-2.5

Blasting Notes:	Number of Sticks
Heading: First Round: 6 sticks, 60%, in each cut hole, cut generally blasted twice	36 to 72
Second Round: 3 side holes each side, 5 sticks, 40% each	30
Third Round: Rest of side holes and dry holes, 5 sticks, 40% each	40
Stub holes, say	5 to 15
Total Sticks	111 to 157
Total Pounds	93 to 131
Sub-bench: 4 widening holes; 2 to 3 sticks each, 40%	10 to 12
6 down holes; 5 to 7 sticks, each, 40%	30 to 42
Bench: 6 holes; 6 to 8 sticks each, 40%	36 to 48
Taking up bottom, average, say	15
Total Sticks	91 to 117
Total Pound	76 to 97

FIG. 1.





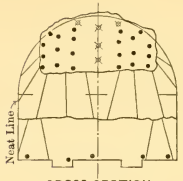


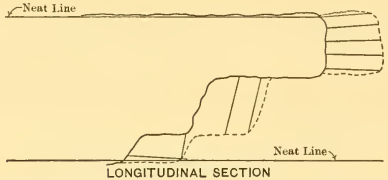
Drilling Method, No.2: Five drills in heading, mounted on three columns; the holes marked with a cross (X) were drilled with the drills on the center column

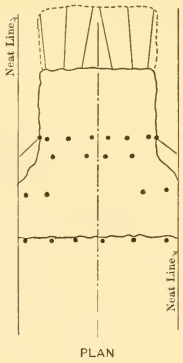
	Per Round				Per Cubic Yard		Per Linear Foot of Tunnel		
	Total Depth Drilled	No. of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No. of Feet Drilled	Pounds of Dynamite
Heading	190-220	35-42	134-196	6½-8	5.4-6.0	3.9-5.0	5.3	28 to 32.	20.7-26.5
Bench	110-130	55	79-106	4	2.-2.4	1.4-2.0	13.7	27. - 33.	19.2-27.4
						Total	19	55. - 65.	39.9-53.9
						Per cubic yard, whole tunnel section		2.9 - 3.4.	2.1-2.8

Blasting Notes:	Number of Sticks
Heading: First Round; 2 to 3 relieving holes sprung with 4 to 5 sticks each	8 to 15
8 cut holes, 7 sticks each (sometimes shot twice)	56 to 112
First side round, 6 holes, 6 sticks each	36
Widening and dry holes, 10 to 12 holes, 6 sticks each	60 to 72
Total Sticks	160 to 235
Total Pounds	134 to 196
Sub-bench: 8 holes, 4 to 6 sticks each	32 to 48
Bench: 8 holes, 6 to 8 sticks each	48 to 64
Taking up bottom, average	15
Total Sticks	95 to 127
Total Pounds	79 to 109

FIG. 2.





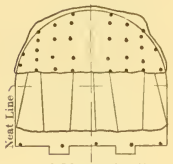


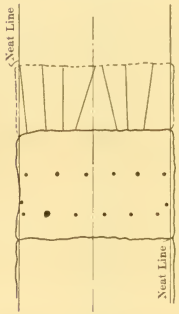
Drilling Method No.3: Heading same as second method, but larger lift taken off bench, and lift holes drilled in bottom bench in order to get down to grade in floor. Bench kept closer to heading.

	Per Round				Per Cubic Yard		Per Linear Foot of Tunnel		
	Total Depth Drilled	No. of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No. of Feet Drilled	Pounds of Dynamite
Heading	190 to 220	35 to 42	134 to 196	6½ to 8	5.4 to 6.0	3.9 to 5.0	5.3	28 to 32	20.7 to 26.5
Bench	145 " 190	90 to 110	118 " 167	6½ " 8	1.6 " 1.9	1.3 " 1.8	13.7	22 " 36	17.8 " 24.7
						Total	19	50 " 58	38.5 " 51.2
						Per cubic yard, whole tunnel section		2.6 " 3.1	2.0 " 2.6

Blasting Notes:	Number of Sticks
Heading: First Round: 2 to 3 relieving holes sprung, with 4 to 5 sticks each	8 to 15
8 cut holes, 7 sticks each (sometimes shot twice)	56 to 112
First side round, 6 holes, 6 sticks each	36
Widening and dry holes, 10 to 12 holes, 6 sticks each	60 to 72
Total Sticks	160 to 235
Total Pounds	134 to 196
Sub-bench: 4 widening holes, 4 to 5 sticks each, 2 rounds	32 to 40
6 down holes, 5 to 7 sticks each, 2 rounds	60 to 84
Bench: 4 down holes, 5 to 7 sticks each	20 to 28
6 to 8 lift holes, 5 to 6 sticks each	30 to 48
Total Sticks	142 to 200
Total Pounds	118 to 167

FIG. 3.





Drilling Method No.4: 8 drills on 4 columns used in heading. Bench taken off in one lift. Bottom taken up with lift holes

	Per Round				Per Cubic Yd.		Per Linear Foot of Tunnel		
	Total Depth Drilled	No. of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No. of Feet Drilled	Pounds of Dynamite
Heading	310-320	63-71	215-357	8-9	4.5-5.1	3.4-5.7	7.9	35.6-45.	26.9-45.0
Bench	190-210	89-100	107-155	8-9	1.9-2.2	1.2-1.7	11.1	21.1-24.	13.3-18.9
						Total	19	56.7 69.	40.2-63.9
						Per cubic yard, whole tunnel section		3.-3.6	2.1-3.4

Blasting Notes:	Number of Sticks
All holes of whole round are cleaned and loaded before blasting is started	
First Round:5-6 lift holes,7 to 9 sticks each	35 to 54
First row,sub-bench,6 holes,6 to 8 sticks each	36 to 48
Second Round:Second row,sub-bench and widening holes,8 to 10 holes, 6 to 8 sticks each	48 to 64
Stub holes	10 to 20
Bench Total Sticks	129 to 186
Total Pounds	107 to 155
Third Round:8 cut holes,7 sticks each,often requires 3 to 4 charges	112 to 224
Fourth Round:8 holes,First side round,5 to 7 sticks each	40 to 56
Fifth Round.8 holes,Second side round,5 to 7 sticks each	40 to 56
2 dry holes 5 to 7 sticks each	10 to 14
Sixth Round.4 to 6 widening holes and dry holes,6 sticks each	36 to 48
Stub holes	20 to 30
Heading Total Sticks	258 to 423
Total Pounds	215 to 357

FIG. 4.

The average quantity of powder used on the whole work was about 2.9 lb. per cu. yd. The tables on the diagrams, Figs. 1, 2, 3, and 4, show that the quantity actually used in making the advance at the main working faces was about 2.5 lb. The difference is accounted for by the larger percentage of powder used for trimming the sides, breaking out the cross-passages between the tunnels, and the excavation of the ditches, the latter operation not being done until the concrete lining was about to be put in.

There was some time, too, during the earlier stages of the work, when it is believed that an excessive quantity of powder was used; for one or two months it ran up to 4 lb. per cu. yd.

MUCK CAR USED AT WEEHAWKEN SHAFT

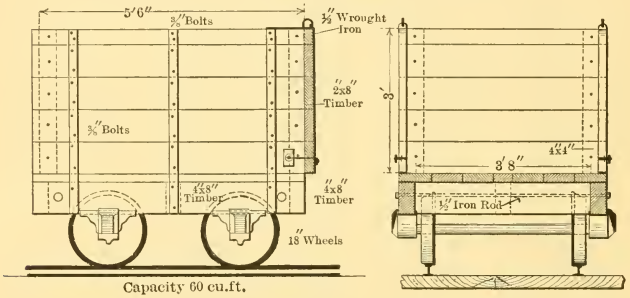


FIG. 5.

The dynamite used was "Forcite." At first, both 40% and 60% were used, the 60% generally only for blasting the cut in the headings; during the latter part of the work, however, the 60% was used exclusively.

The rock as a rule broke very well, and only a comparatively small quantity could not be handled by the shovels without being broken up further by block-holing. In the sandstone the quantity of powder per cubic yard was much more than for any of the trap.

In drilling the Central Shaft, a 6-hole cut was made approximately on the center line, east and west, the enlargement requiring about 18 more holes, which were generally about 6 ft. deep, the average advance being about 4 ft. per day of 24 hours.

The drills were run by steam until a depth of about 150 ft. had been reached, air from the plant at Hackensack being available after

PROGRESS PROFILES OF NORTH AND SOUTH TUNNELS
SHOWING MONTHLY EXCAVATION

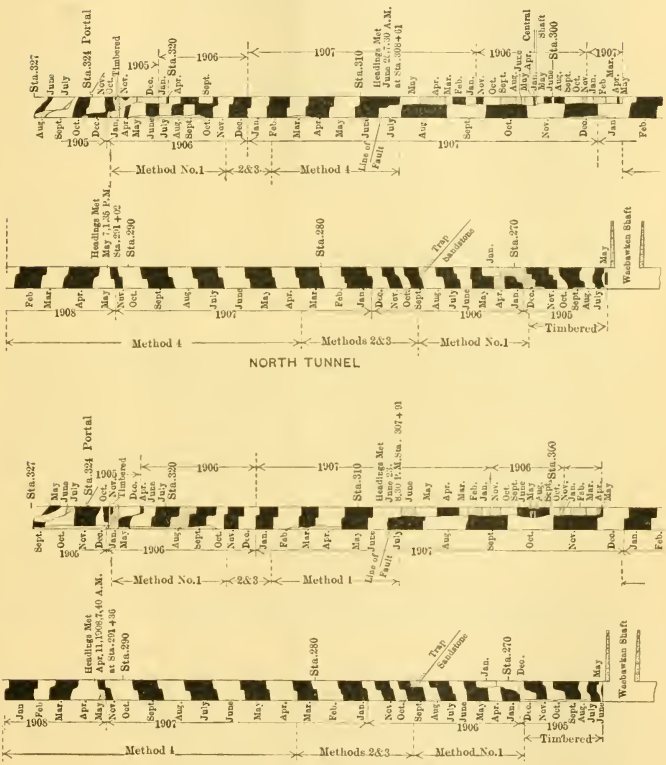


FIG. 6.

that time. Four drills were used most of the time, and six later when air was available. This work was done entirely by the John Shields Construction Company, and a depth of 205 ft. was sunk in 6 months (from July 15th, 1905, to January 15th, 1906). A derrick was used for hoisting and lowering men and tools during the sinking, elevators being put in later.

Drilling Data.—During the progress of the work, both general and detailed observations were made of the drilling, the results of which are shown in the tables. Table 1 has been compiled from the records as platted daily on the chart from the inspectors' reports, as shown by Plate XXIII, and described on page 113. Table 2 contains some data relating to the drilling in the headings.

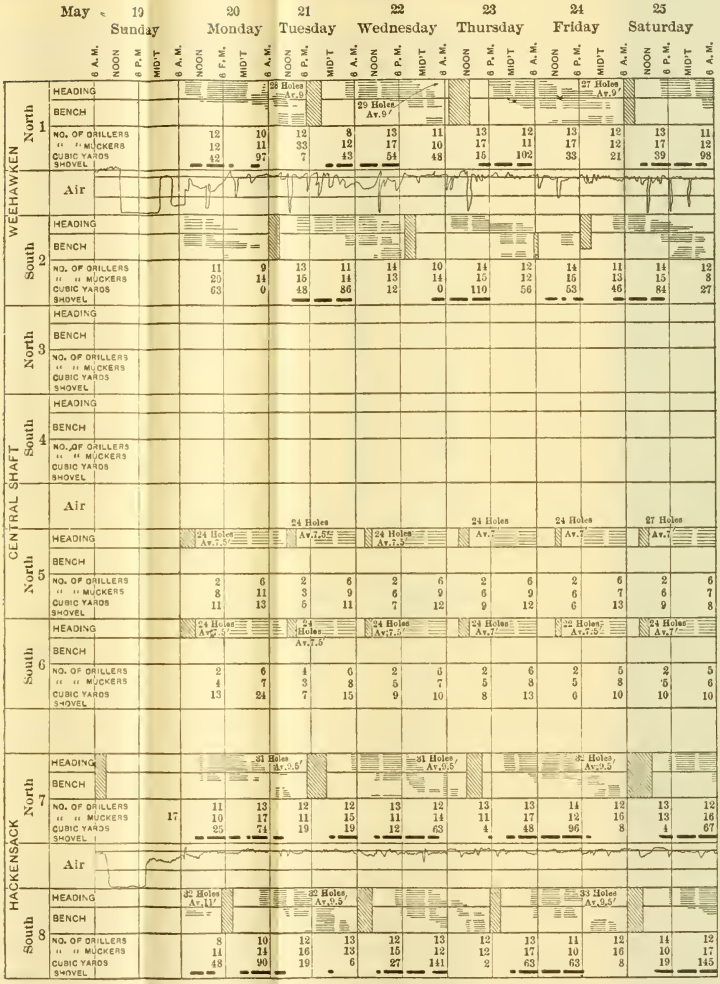
The general results of these observations show that the average time the drills were "actually working" was 5.2 hours per shift, and that they were actually "hitting the rock" about half of this time, or about 2.5 hours per shift. The average depth drilled per hour, during the time the drills were "actually working," was 2.66 ft.

The "actual working time," as noted above, covers the period from the time the drills were first set up in the heading after blasting until they were taken down for the next blast; it does not include the time occupied in setting up or taking down, which would probably average 30 min. more per shift. It is believed that this figure will also apply very closely to drills working on the bench, though no actual observations were taken to determine this, on account of the irregularity with which they were worked.

The actual working time of the drills in the 736 shifts (7 360 hours) covered by Table 1, was 3 826 hours, or 5.2 hours per shift. The average depth drilled per yard, as shown in the last column of Table 1, agrees fairly well with the figures on the diagrams, Figs. 1, 2, 3, and 4.

Table 2 has been compiled from detailed timed observations of individual drilling of down holes in the bench, for periods of 7 or 8 hours each, in January, 1907. The work at that time was in fairly normal condition at all points.

The figures in the third column of Table 2 include the time required for moving from one hole to another, when this occurred during the observation, the time required for changing bits, oiling drills, etc., and all delays of all kinds. A close record of the delays was



RECORD OF DRILLING, AIR PRESSURE, MUCKING, ETC.

kept, and it was considered that, of the 93 hours, 48 min., in Table 2, the unnecessary delays amounted to 5 hours, 7 min., or about 5½ per cent.

TABLE 1.

Method.	Date.	Number of shifts covered by observations.	Place.	Average number of hours worked per shift.	Average depth drilled per hour per drill.	Average depth drilled per yard.
No. 1—4-drill.....	Aug. '06	44	Hackensack, N.	5.69	2.78	10.1
	Sept. '06	33	" N.	5.80	3.77	11.1
	Aug. '06	43	" S.	5.60	2.89	9.1
	Sept. '06	36	" S.	6.18	2.65	8.7
	Jan. '07	16	Central Shaft E. N.	5.99	2.99	8.2
	Jan. '07	20	" S.	6.05	2.9	7.1
	Apr. '07	48	Central Shaft W. N.	4.92	3.3	6.7
	Apr. '07	48	" S.	5.00	3.2	7.7
Nos. 2 and 3—5-drill.....	Dec. '06	54	Weehawken, N.	4.95	2.16	4.52
	Dec. '06	54	" S.	5.23	2.14	4.54
	Dec. '06	52	Hackensack, N.	5.03	2.2	5.77
	Dec. '06	54	" S.	5.90	1.82	5.67
No. 4—7-drill.....	June '07	56	Weehawken, N.	4.77	2.55	4.23
	June '07	58	" S.	4.82	2.26	3.88
8-drill.....	May '07	60	Hackensack, N.	4.67	2.44	5.00
	May '07	60	" S.	4.54	2.57	4.80

TABLE 2.

Date.	Place.	Total working time.		Number of feet drilled.
		Hours.	Minutes.	
Jan. 14th, 1907.....	Weehawken N.....	8	0	15
" 15th, 1907.....	" N.....	7	32	12
	" N.....	7	22	14
" 12th, 1907.....	" S.....	8	0	20
	" S.....	8	0	11
	" S.....	8	0	10
" 11th, 1907.....	Hackensack N.....	8	0	13
" 17th, 1907.....	" N.....	7	10	10
	" N.....	7	5	11
	" N.....	7	10	10
" 16th, 1907.....	" S.....	4	20	10
	" S.....	6	9	10
	" S.....	7	..	8
Totals.....	.....	93	48	154

Average: 36.6 min. per ft. drilled, or 1.64 ft. drilled per hour.

As a check on the average figures obtained from various sources, the following estimate of the cost of drilling per cubic yard was made up from these average figures, for comparison with the actual average cost on the whole work. The cost records show this to be about $2.25 per yd., exclusive of power for running the drills, almost exactly what

the following estimates give for theoretical average conditions, although no effort was made to have this latter compare so closely.

Estimated Cost per Drill per Day.

Drill Runner	1	at	$3.50	per day,	$3.50
Helper	1	"	2.00	" "	2.00
Nipper	$\frac{1}{3}$	"	1.75	" "	0.35
Heading foreman	$\frac{1}{12}$	"	5.00	" "	0.42
Walking boss	$\frac{1}{50}$	"	7.50	" "	0.15
Blacksmith	$\frac{1}{12}$	"	4.00	" "	0.34
Blacksmith helper	$\frac{1}{12}$	"	2.00	" "	0.16
Machinist	$\frac{1}{12}$	"	3.00	" "	0.25
Machinist helper	$\frac{1}{24}$	"	1.75	" "	0.07
Pipe fitter and helper	$\frac{1}{50}$	"	5.00	" "	0.10
Oil, waste, blacksmith coal, etc.					0.24
Drill steel, 6 in. per shift					0.20
					$7.78

Average number of feet drilled per cubic yard ..... 3 to 3.5
Number of feet drilled per drill, per shift ..... 10.5 to 12
Number of yards per drill, per shift ..... 3.5±

Cost of drilling, per yard, $\frac{\$7.78}{3.5}$ ..... $2.22±

In all the foregoing tables and computations, the quantities used have been those paid for. The quantity taken out, however, has been 10% more than that paid for, and 28% more than the contractor was actually required to take out.

The specifications required that the excavation should be taken entirely outside of the neat line, as shown on Plate VIII of the paper by Mr. Jacobs, but not necessarily beyond this line, but that the contractor would be paid for rock out to the standard section line, which is 1 ft. larger on the sides and top and 6 in. deeper in the bottom than the neat line.

A great deal of the extra quantity was due to rock falling from the core-wall side whenever one working face was behind the other. Blasting at the face behind generally loosened more or less rock on the core-wall side of the tunnel which was ahead, in one or two instances breaking entirely through, as shown in Fig. 2, Plate XXVI, the hole in the core-wall in this case being utilized by building a storage chamber in it.

Table 3 gives some of the statistics of drilling in the Simplon Tunnel, as compared with the drilling on this work, the figures for the Simplon being taken from papers read before the Institution of Civil Engineers of Great Britain.

TABLE 3.

	Bergen Hill.	Simplon.
Drills set up in heading, percentage of total elapsed time	50%	60%
Actually drilling the rock, percentage of total elapsed time	25%	50%
Average advance per round (attack)	8.5 ft.	3.8 ft
Average time for each attack	36 hours.	5 hours.
Average advance per day of 24 hours	5 ft.	18 ft.†
Depth of holes	10 ft.	4.6 ft.
Diameter of holes	2⅜ in.	2⅜ in.
Linear feet drilled per hour, per drill	2.7	7.0
Linear feet drilled per cubic yard	5.0	6.0
Pounds of dynamite per cubic yard	3.4 to 5.7	8½
Average depth drilled with one sharpening	12 in.	6½ in.
Total number of men per day of 24 hours*	450	3 300

*On Bergen Hill Tunnels, for two full working faces at the Hackensack end, about 3 000 ft. in from portal (March, 1908). At Simplon, two full faces and two headings, at a distance of about 5 000 ft. in from the portal (January, 1900). These both include lining as well as excavation. The lining of the Bergen Hill Tunnels progressed about twice as fast as the excavation; it is inferred that on the Simplon it progressed at about the same rate as the excavation.

†At the Italian end, in Antigoric gneiss, which is stated to be very hard rock.

The figures in Table 3 are for "heading only" in both cases, except for the last item (number of men), the heading in the Simplon Tunnels being about 60 sq. ft., as compared with the heading of Method No 4 (which has been used for comparison), of 210 sq. ft.

Mucking and Disposal.—The conditions affecting the disposal of the muck, after blasting, were quite different at the two ends, the grade descending in the direction of the loads at Weehawken and ascending at the Hackensack end. At the Weehawken end the mouth of the tunnels was at the bottom of a shaft some 80 ft. deep, Fig. 2, Plate XXII, the muck in the tunnel cars being hoisted by elevators to a platform at the top from which it was dumped into standard-gauge cars supplied by the Erie Railroad, as shown by Fig. 7; or later hauled to the crusher or storage pile, some 500 ft. distant, on the north side of Baldwin Avenue. At the western end, the cars were hauled directly to the surface through the approach cut, and the material, except that required for concrete and rock packing, was deposited in the embankment across the Hackensack Meadows, a haul of from 1 000 to 3 000 ft. beyond the portal.

All disposal tracks were of 3-ft. gauge, the main running tracks being generally laid with 60-lb. second-hand rails, although some of lighter weight were used.

Except for about 1 000 ft. in each tunnel at the Weehawken end, where the muck was loaded by hand, four steam shovels, operated by compressed air, were used, one at each working face. One of these was a "Marion, Model No. 20," weighing 38 tons, the others were "Vulcan Little Giant," of about 30 tons each. All these shovels were on standard-gauge track, and were moved back from 300 to 500 ft. from the working face during blasting.

At Weehawken, previous to the time the shovels were installed, the muck was shoveled by hand into the cars from the bottom of the bench, and the heading muck was dumped into them from the movable platform (Jumbo) shown by Fig. 1, Plate XXII. There were three loading tracks at the face. The cars used at that time were

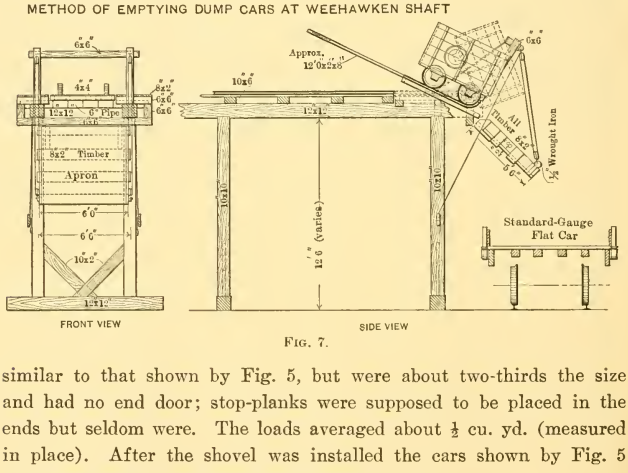


FIG. 7.

similar to that shown by Fig. 5, but were about two-thirds the size and had no end door; stop-planks were supposed to be placed in the ends but seldom were. The loads averaged about ½ cu. yd. (measured in place). After the shovel was installed the cars shown by Fig. 5 were used, and the loads averaged nearly 1 cu. yd.

The empty cars were pushed up to the shovel by hand from the storage track. When loaded, they were given a start with the bucket of the shovel, and were then allowed to coast by gravity out to the storage track near the shaft, where they were stopped by placing rolls of cement bags or burlap on the rails. After the lining was started, the loaded cars were stopped on the inside of the lining and only sent out over the single track through this latter at stated intervals,

when several cars followed in close succession, with a long interval which permitted the concrete to be brought in. The empty cars were hauled back to the storage track near the working face by mules, one mule usually hauling two cars at a time.

Up to the time the trap rock was reached, about 1 100 ft. from the shaft, the excavated material was disposed of by loading it on flat cars. All the trap, however, was stored to be used later for concrete and ballast.

When the tunnels were in full working order, sixty muck cars of the type shown by Fig. 5, were in use, about evenly divided between the two tunnels. For some time the work was greatly hampered by lack of cars, and even with the sixty finally obtained, there were many times when extra cars could have been used to advantage to keep the shovel working.

When mucking by hand, the mucking gangs consisted of from 15 to 20 men. The maximum output was 50 cu. yd., and averaged about 35 cu. yd. per shift; there was a great deal of trouble in keeping the gangs full, as labor at that time was very scarce, and the tunnels were quite wet. The maximum output of either of the shovels was 159 cu. yd. in one shift, and the best average in any month—which was between July and December, 1907, during which time only the enlargement and bench of the Central Shaft headings was being taken out from the western end—was 60 cu. yd. per shift. As the shovels were generally idle for one shift out of three, the quantity actually handled averaged 90 cu. yd. per shift during the shifts the shovel worked. All these quantities were "measured in place," and, as previously noted, would be about equal to twice as much measured loose in the cars.

The shovels at both ends were usually worked with three crews for the two tunnels; two day crews, one at each shovel, and a night crew which was used in either tunnel as occasion required. The day crews generally averaged from 45 to 60 hours overtime during the month, one of them working during the early part of the evenings in the opposite tunnel to the night crew. For a short time, when the ventilation at the western end was very bad, four crews were worked, day and night crews in each tunnel; but, as a general rule, the method of working three crews was preferred by the men, and was less expensive for the contractor.

At the Hackensack end, 4-yd., Allison, one-way, dump cars were used, being handled by "dinky" locomotives, of which there were three in use up to October, 1907, and four after that. One 15-ton Porter engine, with 10 by 16-in. cylinders, was used outside the tunnels for handling the trains (from 6 to 8 cars) on the dumps and to the crusher; the other three, 12-ton Vulcans, 9 by 14-in., were used in the tunnels. About 30 dump cars were in use, and of these there were generally from 3 to 6 under repair.

Generally, 4 cars were hauled out together, although 5 and occasionally 6 were handled. The work was generally arranged so that the heavy mucking shift alternated in the two tunnels, the two engines being worked there and a single engine in the other tunnel.

The tunnel engines left the cars on a track just outside the portal, from which they were made up into trains of from 6 to 8 cars and taken to the dump or crusher by the large "dinky."

The muck from the Central Shaft headings was loaded by hand into cars similar to that shown by Fig. 5, but smaller and having no door at the forward end. A double elevator took the cars to a platform about 20 ft. above the surface, where they were dumped by revolving platforms, similar to those at Weehawken, into storage bins or directly into wagons. The muck was all hauled away in wagons; part of it was used to fill some vacant lots, and part was hauled to the crusher at the Western Portal.

The method under which the best results were obtained was that in which a full round was blasted every 36 hours, securing an advance of practically 9 ft. of full section. During the first shift of the three, as soon as the blasting had been completed and lights strung, the shovel was moved forward, and cleaned up the floor to the main pile of muck, the material from the blast being scattered from 150 to 300 ft. back from the face; during this shift, also, the drillers mucked the heading and set up their drills, the muckers helping to carry in the columns and drills. During the second shift the main pile of muck was disposed of, leaving not more than 2 or 3 hours' work for the shovel on the third shift. This left nearly the whole of the third shift for drilling the lift holes.

Ventilation.—At Weehawken considerable difficulty was caused by fog and smoke accumulating in the tunnels after blasting. This was generally worse on days when the barometric pressure was low out-

side, and worse in the North than in the South Tunnel. A 6-ft. fan, driven by an electric motor, was installed in the cross-passage at Station 274, 900 ft. from the shaft, the headings at that time being about 300 ft. in advance of this point, to force the air from the South into the North Tunnel, drawing it in at the mouth of the South Tunnel and discharging it at the mouth of the North Tunnel, thus insuring a circulation in both tunnels, as shown in plan by Fig. 8.

This necessitated, of course, that the cross-passages between that in which the fan was placed and the mouths of the tunnels should be blocked tight. There was some difficulty in keeping this blocking tight, owing to the force of the blasting blowing out the bulkheads. The fan, however, did good service when it and the bulkheads were in good order. The compressed air discharged from the drills kept the headings fairly clear, as well as that part of the tunnel between the headings and the fan. The fan was moved ahead to the next cross-

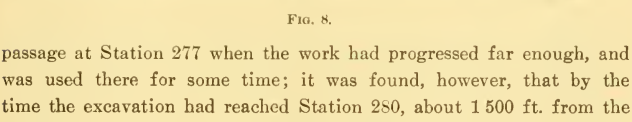


FIG. 8.

passage at Station 277 when the work had progressed far enough, and was used there for some time; it was found, however, that by the time the excavation had reached Station 280, about 1 500 ft. from the shaft, there was practically no further difficulty from fog and smoke. No satisfactory explanation was found for this, as it would rather be expected that the ventilation and trouble with smoke and fumes from blasting would be worse as the distance increased between the mouth of the tunnel and the working face. One explanation was offered: That the blasting of the softer sandstone tended to create more and lighter dust than the heavier trap rock; whether or not this was so, it is a fact that there was far less trouble with fog and smoke after the sandstone was passed.

At Hackensack, the principal cause of trouble was the smoke from the "dinky" locomotives. As the tunnels progressed, this gradually became worse, until a connection was made with the Central Shaft headings. A fan was installed in the cross-passage at Station

316 (700 ft. in from the portal), but was never worked properly. Apparently, the men, at least the walking bosses and foremen, had little faith in the fan as a means of ventilation; no real attempt was made to keep it in order or operate it properly, and a great deal of time and money was lost groping around in the smoke and fog, the density of which increased, not only with the state of the atmosphere, but also with the direction of the wind. On some days the tunnels easily cleared themselves, and on others the smoke was so thick that a candle held at arm's length could not be seen. At this end, the South Tunnel was generally worse than the North. After the headings were holed through between the portal and the Central Shaft there was very little trouble, there being usually a strong up-draft through the shaft. This was so pronounced when the wind was blowing toward the portal, that the moisture-laden air, as it ascended from the mouth of the shaft, presented the appearance of a heavy rainstorm with the rain ascending instead of descending. When the wind was blowing away from the portal, that is, from the southeast, the effect of the shaft as a chimney was neutralized, and, consequently, the smoke accumulated in the tunnels. To overcome this, a large blower, with a fan 9 ft. in diameter, and with blades 4 ft. wide and 2 ft. 3 in. long, operated by a vertical 12-h.p. engine, was installed at the top of the shaft, and this kept the tunnels reasonably clear of smoke at all times. After the bench and enlargement had passed the bottom of the shaft, the use of the fan was abandoned, as it was found that the tunnels cleared themselves fairly well, probably owing to the larger cross-section reaching all the way to the Shaft. What little fog and smoke there might be did not cause enough trouble to warrant the cost of running the fan, which, owing to its location, required the whole time of a mechanic in attendance day and night.

Lighting.—During the earlier stages of the work, gasoline lamps and Kitson lights were used. The former, of the familiar banjo type, and a modification of this, with a section of wrought-iron pipe for the reservoir, were very unsatisfactory, and were out of repair and leaking a large proportion of the time. The Kitson lights were given only a short trial, but were found unsatisfactory, owing to the necessity of moving them frequently and having to set them up in insecure positions. Electric lights were installed by Mr. Bradley, on his assumption of the contract.

The number of lamps maintained in each of the tunnels for the excavation was approximately as follows:

At the main working face	From	8 to 10
On and around the shovel	"	9 to 12
Between the portal and the working face	"	60 to 80

The cost of lighting for the whole work averaged about 15 cents per cu. yd., which is quite large. This was mainly due to the fact that current was bought from outside sources during a large part of the time (one-third of the yardage). Part of this current cost 5 cents per kw-hr., and there were fairly heavy charges for connecting the tunnel wiring system with the source of supply. Current bought from the Public Service Corporation cost from 10 to 12 cents per kw-hr. delivered at the mouth of the tunnel.

Pumping.—The quantity of water encountered during the excavation of the tunnels, measured somewhat roughly, was approximately as follows:

At Weehawken	74 gal. per min.
At Central Shaft	1 " " "
At Hackensack	18 " " "

The water at the Weehawken end had to be pumped from the bottom of the shaft, a lift of about 90 ft., while at the Hackensack end it had to be pumped back from the face up grade to the portal.

The cost of pumping was about $100 to $125 per month for labor for the whole work, besides the cost of the plant (about $1 200) and the power for running it.

Progress.

The total time elapsed from the time of starting work at the Weehawken end, in May, 1905, to the completion of the excavation, in May, 1908, was almost exactly three years. Of this time about 40 days were lost in February and March, 1906, when work was stopped by the Receiver of the Shields Company, the total number of days actually worked being about 940, giving an average progress of 6.26 ft. per working day in each of the two tunnels, which, omitting the Central Shaft headings, gives an average rate of progress for each working face, of 3.13 ft. per day.

These 940 days include practically all the time elapsed, except Sundays and such few holidays as were observed. For some of this time, work was being carried on at only one or two points; the time, therefore, represents practically the total possible working time during the period covered.

Progress at Weehawken.—At Weehawken the total number of days worked was 763, divided as follows:

186 days in timbered section, about 426 ft., an average rate of 2.3 ft. per day in each tunnel;

176 days in hard sandstone, about 563 ft., an average rate of 3.2 ft. per day in each tunnel;

112 days in hard trap, about 267 ft., an average rate of 2.4 ft. per day in each tunnel;

289 days in ordinary trap, about 1 316 ft., an average rate of 4.55 ft. per day in each tunnel.

Progress at Central Shaft.—At Central Shaft the average length driven per day in each of the four headings is shown by Table 4.

TABLE 4.

Location.	Number of days worked.	Total length of heading, in feet.	Average length of heading driven per day worked, in feet.
N. E.	227	446	1.96
S. E.	168	346	2.06
N. W.	272	768	2.82
S. W.	234	698	2.98

Progress at Hackensack.—At Hackensack the total number of days worked on the tunnels proper, all in trap rock (omitting the cut and cover) was about 792, divided as shown in Table 5.

TABLE 5.

Location.	Number of days worked.	Advance.	Average advance per day.
Station 323 to Central Shaft headings	492	1 450	4.5
Bench and enlargement of Central Shaft headings	159	{ 1 150* / 906†	7.2* / 5.7†
Central Shaft headings to Weehawken headings	141	620	4.4

* Actual advance. † Equivalent linear feet of full section tunnel.

The best month's work in each location was as follows, the actual yardage excavated and paid for being reduced to equivalent linear feet of full section. The tunnels were generally taken out to full section, except for a small amount left in the bottom, which latter reduced the equivalent linear feet of full section to about 95% of the actual advance at the face.

Weehawken.—

			Linear feet.	Feet per day.
Full timbered section,	North Tunnel	..Nov., 1905,	87	= 3.0
Sandstone	" "	..May, 1906,	109	= 3.9
Trap (normal)	South "	..July, 1907,	144	= 5.3

Hackensack (All trap).—

		Linear feet.	Feet per day.
Portal to Central Shaft headings,	South Tunnel ..May, 1907,	139	= 5.0
*Enlargement of headings,	" " ..Nov., 1907,	175	= 6.0
Central Shaft headings to Weehawken headings, North Tunnel	..Apr., 1908,	145	= 5.2

Central Shaft Headings.—During April, 1907, 122 lin. ft. of heading, averaging 3.8 cu. yd. per lin. ft., were taken out in the South Tunnel, west of the shaft. This was equal to 5.0 ft. per day for the 24 days worked.

The Best Week's Work.—The best week's work at either of the main working faces, when the full section was being excavated in trap rock, was 803 cu. yd., equal to 41.8 lin. ft. of full-section tunnel, or an average of 6.0 lin. ft. of full section per day; this was from the South Tunnel at Hackensack for the week ending January 11th, 1908.

The Best Yardage.—The largest number of yards taken out in any one week from one working face was 1 087, equivalent to 56.6 lin. ft. of full section, or an average of 8.1 lin. ft. of full section per day. This was bench and enlargement only (Central Shaft headings) in the North Tunnel, Hackensack, for the week ending October 19th, 1907.

The largest yardage for the whole work in any one week was 3 238 cu. yd. from four working faces—two at Weehawken in full section and

* The actual advance of the bench this month was 202 lin. ft.

two at the Hackensack bench and enlargement (Central Shaft headings). This was equivalent to 168.4 lin. ft. of full-section tunnel, or an average of 6 ft. per day from each working face.

The Best Month's Work.—The best month's work with each of the four methods of drilling the headings, as shown in Figs. 1, 2, 3, and 4, where the work was straight forward and the full section was being taken out, was as follows:

Method No. 1	About	90 ft.	in sandstone.
" No. 2	"	100 "	in trap.
" No. 3	"	137 "	in trap.
" No. 4	"	145 "	in trap.

In regard to these figures it should be noted, as stated previously, that the organization of the men and plant was not properly completed until near the time Method No. 4 was put in operation.

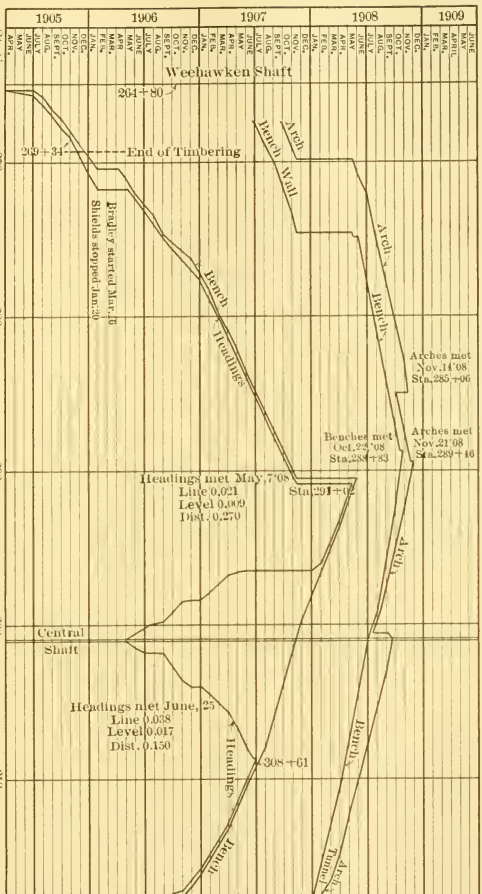
In Fig. 9 is shown graphically the relation of the progress to the time elapsed in the North Tunnel, the diagram for the South Tunnel being almost exactly the same.

Plant.

The plant installed by the John Shields Construction Company, and taken over by Mr. Bradley, was composed very largely of second-hand material, and eventually most of it had to be replaced. Insufficient and inefficient plant and delay in installation were largely responsible for the small progress made by the Shields Company, and Mr. Bradley's endeavor to utilize this plant not only caused much delay during the first 8 or 10 months after he started work, but also involved large expense.

Power Plant.—At Weehawken the plant installed by the Shields Company consisted of three old locomotive boilers, each having a nominal capacity of about 125 h.p., and one Rand and one Ingersoll-Sergeant compressor, each of a rated capacity of about 1 250 cu. ft. of free air per min. compressed to 100 lb.

To this Mr. Bradley added two more second-hand locomotive boilers, and another Rand compressor of the same type and capacity as the first. The theoretical steam capacity of each of the five old locomotive boilers was about 4 250 lb. per hour, or a total capacity of 21 250 lb. per hour.



PROGRESS PROFILE—NORTH TUNNEL

Fig. 9.

Theoretically, the demand on this steam was:

		Pounds per hour.
Three compressors, about 5 600 lb. per hour each		16 800
One dynamo	About	1 000
One 500-gal. pump	"	1 000
One hoisting engine for elevators	"	2 000
Total		20 800

Actually, there was considerable deficiency of steam when an endeavor was made to work the three compressors at their full capacity. A separate boiler was afterward installed to run the hoisting engine for the elevators and the pumps, thus leaving a requirement of only approximately 18 000 lb. of steam per hour, but even this was beyond the capacity of the boilers, especially as one was almost always out of commission.

The two Rand compressors were 24 by 24 by 30-in., straight-line, one-stage, steam-driven, with a nominal capacity of 1 250 cu. ft. of free air per min. at 80 rev. per min. The Ingersoll-Sergeant was of similar type and capacity. Therefore, the theoretical quantity available was 3 750 cu. ft. of free air per min.

The theoretical air requirements (as taken from manufacturers' catalogues) were:

	Cubic feet of free air per minute.
20 Rand slugger drills (12 by 174)	2 088
2 Little Giant shovels (taking air two-thirds of the time)	1 100
Total	3 188

This estimate, based on the assumption (given in the catalogues) that the drills would be working about three-fifths of the time, and the shovels about two-thirds of the time, left apparently an ample margin between the full capacity of the compressors and the requirements for the drills; as a matter of fact, however, it was seldom that more than 80 lb. of air was available, and the pressure often dropped to 60 or 50 lb. at the compressors. During the time this plant was in use the greatest distance to the drills was about 1 500 ft.

As this plant proved to be entirely inadequate to the demands, an arrangement was made with the O'Rourke Construction Company on

August 17th, 1906, whereby they agreed to supplement the air supply by 1 000 cu. ft. of free air per min. at 100 lb. pressure. This arrangement was not altogether satisfactory, and finally (on December 5th, 1906) an arrangement was made with the same company to supply air up to 4 000 cu. ft. of free air per min. at 100 lb., and the old plant was shut down.

The new plant had been in use previously in the construction of the River Tunnels. The air from it was compressed to 40 lb. by low-pressure machines, one being used all the time and two when necessary. These machines were built by the Ingersoll-Sergeant Company, the engines being of the Corliss duplex type, cross-compound steam, with simple duplex air cylinders, each compressor having a capacity of nearly 4 000 cu. ft. of free air per min. This air, at 40 lb., was delivered to an Ingersoll-Sergeant high-pressure machine, having Corliss cross-compound engines, 14 by 26 by 36-in., with air cylinders of the piston inlet type, 13¼ by 36-in., which compressed it to 100 lb. The capacity of this latter machine, taking air at normal pressure, is 920 cu. ft. of free air per min. working at 85 rev. per min.; by taking the air at 40 lb., and working at a somewhat higher speed, this machine alone supplied all the air used at the Weehawken end (approximately 4 000 ft.) from December, 1906, to November, 1907, and, with very few exceptions, the pressure was steadily maintained at from 90 to 100 lb., there being no break-down of any kind.

At Hackensack the plant taken over by Mr. Bradley consisted of six old locomotive boilers and four Rand compressors, all of the same type as those at Weehawken. To this he added two second-hand marine boilers, each of a stated capacity of about 350 h.p., and two more Rand compressors of the same type and capacity as the others, making the total theoretical steam power available approximately 1 450 h.p., with a compressor capacity of approximately 7 500 cu. ft. of free air per min., equal to about 1 500 h.p., allowing for 15% of loss.

Nowhere near the theoretical steam power was ever developed from the boilers. The tubes of the old locomotive boilers were filled with mud in many cases, and were always leaking. The marine boilers were not properly installed to give the best results, and it was seldom possible to work more than four compressors at once, or to keep the air pressure at the power-house much greater than from 70 to 80 lb. at any time.

This plant had been built by the Shields Company on the meadows alongside the Erie and New York, Susquehanna and Western Railroads, and the foundations were not made sufficiently strong to resist the effect of the vibration caused by the passing trains. It was impossible to keep the steam connections tight, and there was not only the loss of steam due to leaky joints, but positive danger of one of the main steam lines breaking entirely. After attempting to operate this plant for nearly 5 months, Mr. Bradley determined to abandon the site and the boilers, and build a new plant, farther back from the railroad, on solid ground, in such a position that a spur track could be built to a coal trestle in front of the boilers.

Two pairs of Stirling boilers, with a total capacity of 2 000 h.p., were installed. As a rule, at times of maximum demand, three of the boilers were in use; after the Central Shaft was stopped, two were generally sufficient, until, toward the latter part of the excavation, the losses in the transmission of the air made it necessary to keep three going.

Eight compressors (the six old ones with two brought from Weehawken), were installed in the new power-house. All were of the same type, namely, Rand, straight-line, steam-driven, 24 by 24 by 30-in., each with a nominal capacity of 1 250 cu. ft. of free air per min. Seven of these were generally worked to their full capacity in order to keep up the necessary supply of air.

The maximum requirements of air at this end were primarily estimated as follows:

Central Shaft, four headings	24 drills.
Hackensack, two working faces	20 drills.
Total	44 drills.

	Cubic feet of free air per minute.
44 Slugger drills (25 by 174) require	4 350
2 Steam shovels	1 600
Pumps and machine-shop, say	1 000
4 Hoisting engines, placing concrete	2 000
4 Derricks	2 000
Total	10 950

The theoretical capacity of the whole eight compressors was:

$$1\,250 \times 8 = 10\,000 \text{ cu. ft. of free air per min.}$$

It was considered that not more than two-thirds of the above equipment would be working at the same time; the actual requirement, therefore, was taken at about 8 000 cu. ft. of free air per min., thus leaving a margin of one spare compressor.

As actually worked out, there were probably never more than eight drills working at any one time at the Central Shaft, and this work was entirely suspended in June, 1907, before there was any demand for power in connection with the tunnel lining. The heaviest actual requirement, therefore, was approximately as follows:

(*A*) *Previous to June 25th, 1907:*

	Cubic feet of free air per minute.
40 Drills (22 by 174)	3 828
2 Shovels	1 600
Pumps and machine-shop, say	1 000
2 Derricks	1 000
Total	7 428

(*B*) *After November, 1907 (after completion of enlargement of Central Shaft headings):*

	Cubic feet of free air per minute.
32 Drills (17 by 174)	2 958
2 Shovels	1 600
Pumps, etc.	1 000
3 Hoisting engines on concrete, each working one-third time	500
2 Derricks	1 000
Total	7 058

The average number of drillers per shift was about 25 at the two main working faces. There were also from 5 to 10 drills trimming and cleaning up for concrete, say an average of 7, making 32 in all.

After November 1st, it actually required three boilers under steam all the time, and not less than seven compressors running at full capacity, to keep the air at proper pressure, the theoretical capac-

ity of the compressors being 8 750 cu. ft. of free air per min., as against 7 000 to 7 400 cu. ft., the theoretical maximum requirement.

Some of this deficiency was due to losses in transmission, part also was due to the fact that the actual was probably considerably below the theoretical capacity of the compressors.

Accidents.

Two accidents occurred to the powder magazines, the causes of which were never absolutely determined. The first occurred on January 10th, 1907, when the dynamite burned up without exploding. The second accident was on March 3d, 1907, when an explosion occurred which damaged property over a very large area, but did not involve any serious injury to persons, only one man being slightly hurt.

The only serious blasting accident in the tunnels occurred on January 26th, 1908, and was due to a premature blast, the cause for which could not be ascertained.

Contractor's Organization.—The work was in general charge of a superintendent, and, during the time it was being carried on at both ends, an assistant superintendent had charge at night. At each end there was a day and a night walking boss, who had general supervision of the men in the tunnels, the day walking boss being the superior, and responsible for the general conduct of the work at his end, both day and night. Two 10-hour shifts were worked, thirteen shifts every two weeks, no work being done on alternate Sundays and Sunday nights. With the exception of the walking bosses and the master mechanic, all the men changed from the day to the night shift every two weeks.

The organization was approximately as follows, for each shift:

General—Both Tunnels.

1 Master mechanic (days only),
1 Machinist,
1 Engine runner,
2 Firemen,
2 Oilers,
1 Electrician and helper,
1 Drill machinist and helper,
3 Blacksmiths and helpers,
1 Powderman,
1 Walking boss,
4 Locomotive engine runners,
4 Brakemen,
1 Switchman,
1 Foreman on dump,
6 Men on dump,
1 Foreman on track,
6 Men on track.

In Each Tunnel.

Drilling and Blasting.	*Mucking.*
1 Foreman,	1 Shovel engineer,
12 Drillers,	1 Cranesman,
12 Helpers,	1 Muck boss,
1 Nipper,	12 Muckers.
1 Pipe-fitter.	

RECORDS.

The records of the work have been based largely on the reports of the day and night inspectors, which were made out on regular forms.

A daily report card was made out each morning and forwarded to the office of the chief engineer. It covered the work done for the previous 24 hours, up to 6 o'clock each morning.

A telephone report was made to the resident engineer by the inspectors each day at 8.30 A. M., giving the conditions, number of men, etc., at the opening of the day's work.

A daily progress profile, on 10 by 10 to the inch cross-section paper, covering the whole length of the tunnels, was kept in the office of the resident engineer. This was mounted in sections, on a piece of composition board, and hung on the wall for convenient reference. The information, showing the progress up to 6 o'clock each morning, was shown on the report of the night inspector, and was plotted on this profile at 7 o'clock each morning. The plotting was left in pencil, and each month's work was colored in. A progress profile was taken by the men of the alignment corps each Saturday morning and plotted by them, alternate weeks being in red and blue ink on the same profile.

A chart showing the number of drills working, time worked, blasting periods, etc. (Plate XXIII), was plotted each morning and was extremely useful, not only in keeping in touch with the work, but in compiling many of the statistics used in the preparation of this paper. These cross-section sheets were ruled 12 by 12 to the inch, thus giving one space per hour horizontally. In the top vertical space are shown the heading drills, their time of stopping and starting, and their number, each heavy line representing one drill. In the next space below are shown the drills on the bench, lift holes, etc.

The blasting time is shown by the portion hatched (shown in red on the original), which covers the whole vertical space when a com-

plete round of both heading and bench is blasted, and only part, top or bottom, as the case might be, if only one or the other. The number of drillers and muckers at the main working face is shown, and below that (in red ink on the original) the number of cubic yards handled each shift. The time the shovel is working is shown by the heavy line filling a whole space; and the air pressure, platted from the recording gauge charts, is shown in the space below.

A combination daily and weekly report, showing the total number of men working on each section, and the number of cubic yards excavated, was entered every day and kept on a filing board in the office of the resident engineer, and a copy was sent to the main office at the end of the week, with such notes on the back as might be necessary, or of interest.

A report was made out weekly and sent to the contractor's superintendent, showing any deviations from grade, any tight places, and the station of bench and headings.

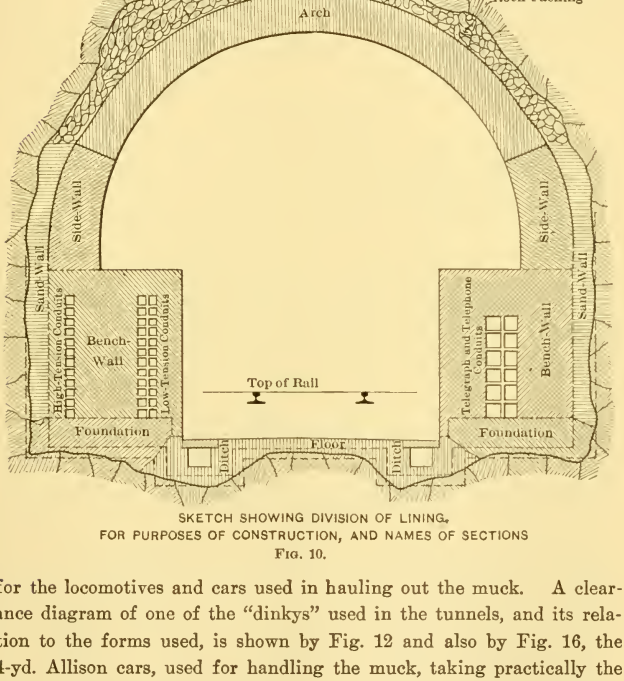
A monthly report was made to the chief engineer, giving detailed statistics of the amount of work done, etc., plant installed, and short notes of any matter of interest affecting the work in any way.

Tunnel Lining.

Preliminary Considerations.—For the placing of the concrete lining, a sub-contract was given to Messrs. King, Rice and Ganey, by Mr. Bradley, which provided substantially that all materials should be supplied by him, and delivered to the sub-contractors at track level, at or near the point in the tunnel at which they were to be placed, and that he would supply light and power; the sub-contractors were to supply the plant, forms, and labor necessary for placing the concrete and water-proofing, building the conduit lines, manholes, etc., etc., to complete the lining, the general form of which is shown on Plate VIII of the paper by Mr Jacobs, and in Fig. 10. The latter also shows the different sections into which the lining was divided for purposes of construction, and the nomenclature adopted for each. It may be noted, incidentally, that the cubic contents of the lining per linear foot of tunnel is almost exactly half the quantity excavated, out to the standard section lines, and as there was some excavation outside of these lines, all of which had to be replaced, the actual quantity of material which had to be brought back into the tunnel

was quite a little more than half the quantity taken out. It will be evident, therefore, that the question of transportation was an important one.

An essential part of the agreement with the sub-contractors provided that the operations incident to the placing of the lining should be carried on so as to provide at all times space for a single track of 3-ft. gauge, running through the work, and the necessary clearance



SKETCH SHOWING DIVISION OF LINING,
FOR PURPOSES OF CONSTRUCTION, AND NAMES OF SECTIONS
FIG. 10.

for the locomotives and cars used in hauling out the muck. A clearance diagram of one of the "dinkys" used in the tunnels, and its relation to the forms used, is shown by Fig. 12 and also by Fig. 16, the 4-yd. Allison cars, used for handling the muck, taking practically the same width, although they were not quite as high. This requirement and the limited space available must be kept in mind in considering the design finally adopted for the forms and plant required in placing

the lining. It should also be kept in mind that, with the rolling stock used, there was only room for a single track through that part of the tunnel where any concrete had been built. As the concrete progressed, therefore, the length of single track was necessarily lengthened, and the problem of transportation was made increasingly difficult.

In working out a design for the bench-wall forms, another highly important and controlling factor, which had to be considered, was the arrangement of the conduit lines, as shown in the general cross-section.*

The quantities of the various materials in the lining, per linear foot of tunnel, were as follows:

Concrete	7.64 cu. yd.
Rock packing: Paid for ..... 1.48 cu. yd.	
Outside standard section line 1.74 " "	
	3.22 " "
Iron and steel	44.2 lb.
Vitrified conduits	84.0 duct ft.
Water-proofing	13.0 sq. ft.
Flags	3.3 " "

General Methods.—The lining was started at both ends of the tunnels before the headings were finally holed through, so that there was practically a separate organization at each end, each in charge of one of the members of the firm. The work at the Weehawken end was started first, and the plant and scheme of working adopted there was thoroughly tried out before the plant for the western end was built, consequently, the latter was somewhat more efficient, being designed in the light of the experience gained at the Weehawken end.

The general sequence of the plan first adopted in placing the concrete is shown by Fig. 10. The concrete was first placed in the foundations up to the elevation of the bottom of the conduit bines, this work, of course, being kept well in advance; next followed, in the order named, the sand-walls, water-proofing, conduits, bench-walls, and finally the arch. The foundation was built in any convenient lengths, multiples of 16 ft., the length of one section of form, the sand-walls in lengths of from 25 to 35 ft., the bench-walls in 25-ft. lengths, and the arch in 10-ft. lengths. Concrete was placed during the day shift only,

*Plate VIII of the paper by Mr. Jacobs.

the forms being moved partly at night, and partly on the alternate days when concrete was not being placed in them.

Five gangs were organized at each end, the first placed concrete in the foundations in both tunnels, as the excavation was ready. In each tunnel there was a gang which built sand-wall one day and bench-wall the next, the two tunnels alternating so that only one bench-wall was built each day, and finally a gang in each tunnel building arches, a 10-ft. section being completed each day. During the night shift, the arch forms and travelers were moved, and all other forms, etc., were made ready for the concrete to be placed the following day. Some of the conduit laying was done by the night shift, but part of it was necessarily done during the day, as the concrete was built up. A small gang was kept busy in both tunnels, during the day shift, laying conduits and water-proofing. The latter two operations were generally performed by the same gang.

This organization, of course, required considerable regularity in the work, and this was finally attained, but at the beginning many sections were often not finished on time, thus creating considerable confusion. The progress possible with this organization (finally maintained with great regularity) was 75 ft. of bench-wall and 60 ft. of arch per week at each of the two working faces in each tunnel. This allowed the bench-wall to gain considerably on the arch, and therefore at a suitable point, as shown on the progress diagram, Fig. 9, a third pair of arches was started, one in each tunnel, increasing the progress on the arches to 180 ft. per week in each tunnel.

Mixing and Transportation.—All the concrete used on this section was mixed in Hains mixers, one being at each end. At the Weehawken shaft the mixer was installed in the framework supporting the head-house and elevators; and storage bins were arranged above, as shown by Fig. 11, *A*, the whole structure being somewhat strengthened to allow this to be done. At the western end the mixer was placed immediately under the bins of the stone crusher, as shown by Fig. 11, *B*, the track below being connected directly with the tunnels. The stone bin under the screen of the crusher plant at the Hackensack end was divided into three parts, the center being filled with sand by a derrick having a clam-shell bucket, the other two with stone directly from the screen above.

This type of mixer proved very efficient on this work. The largest

number of full batches (0.8 cu. yd.) mixed in one plant per hour was about 35; the largest number per day of 10 hours was about 240; but the apparatus was never worked to its full capacity, the quantity of concrete which it was possible to use being limited by other considerations.

The concrete for the foundations was hauled in steel, V-shaped, dumping cars holding about 1 cu. yd., and the concrete for the bench-walls and arches in Stuebner, 1-yd., bottom-dumping buckets placed on small flat cars, as shown by Fig. 1, Plate XXIV. Rock packing was

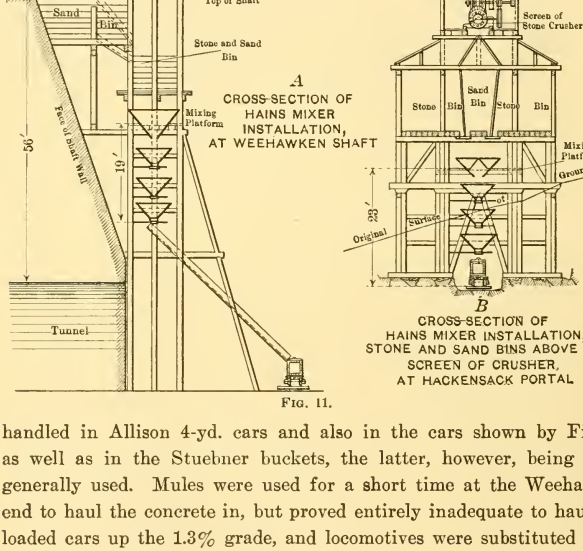
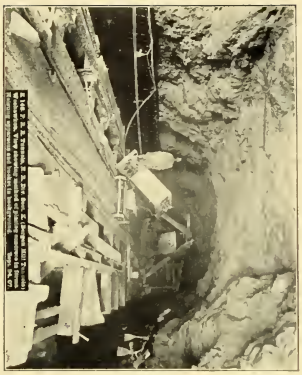


FIG. 11.

handled in Allison 4-yd. cars and also in the cars shown by Fig. 5, as well as in the Stuebner buckets, the latter, however, being most generally used. Mules were used for a short time at the Weehawken end to haul the concrete in, but proved entirely inadequate to haul the loaded cars up the 1.3% grade, and locomotives were substituted after the headings were holed through. At the western end the cars were allowed to coast in, and, up to the time the headings were holed through, were hauled back by mules; after that they were pushed out by a locomotive which had gone in ahead of them. As a rule, from 8 to 10 cars of concrete and rock packing were sent in, one after the other, in proper order, a boy riding on each car and stopping it at the proper place; all these cars were pushed out together when empty.



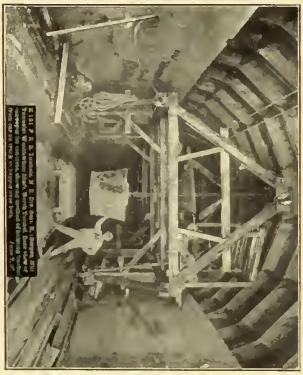


FIG. 1.

FIG. 2.

During the time the excavation was being carried on simultaneously with the lining at the Weehawken end, the rock packing was loaded at the working face and sent out to the point where it was to be used; after that the rock packing was sent in from outside from the reserve pile on the north side of Baldwin Avenue.

At the western end the larger part of the rock packing was sent in from outside, but occasionally, during the time the excavation was going on, the cars from the heading were stopped at convenient points, generally under the gantries, where the lining was being placed, and whatever stone could be utilized was sorted from the top and passed up to the platforms above.

After the headings were holed through, there was considerable difficulty at times in getting a sufficient supply of concrete and rock packing into the tunnel at the time it was required, and while undoubtedly the transportation facilities may have had some influence in this, the principal trouble lay in the difficulty of securing a sufficient supply of proper stone for rock packing, and for the crusher.

While the excavation was progressing, the cars of muck, as they came from the headings, were taken directly to the crusher and dumped into it, the proportion of fine material being fairly constant and the supply regular. At this time, also, a portion of the rock not required at the crusher was dumped along the edge of the bank on the south side of the approach, the larger stones rolling to the bottom where they were easily available to be loaded into cars for rock packing, being entirely free from the fine material; as this stone at the bottom of the bank was used up, the supply was renewed, the rock suitable for rock packing being automatically separated from the fine material as it rolled to the foot of the slope.

After the excavation was completed, however, it was necessary to go into the bulk of the storage piles to get material for the crusher and for rock packing, and then the difficulties were materially increased by the large quantity of fine material encountered, the proportion remaining after the rock packing had been sorted out being too large to send through the crusher. It was not only the handling over of this fine material which caused delay, but the difficulty of disposing of it. On rainy days the trouble was increased by the difficulty of getting men to work in the open.

The delays due to transportation were usually caused by derail-

ments, which were more numerous than they should have been, and were due to the condition of the rolling stock rather than to that of the track. These delays, especially when they occurred in the early part of the day, greatly increased the cost, by necessitating over-time work; a delay of 1 hour in the forenoon generally meant 2 hours' work after 6 o'clock to finish the day's work.

The average number of cars handled (round trips of 1 car) during a day (two 10-hour shifts) at the Hackensack end during January, 1908, when the excavation and lining were in full swing, was about 125 cars of muck and 200 cars of lining material, the former being hauled by locomotives and the latter by mules.

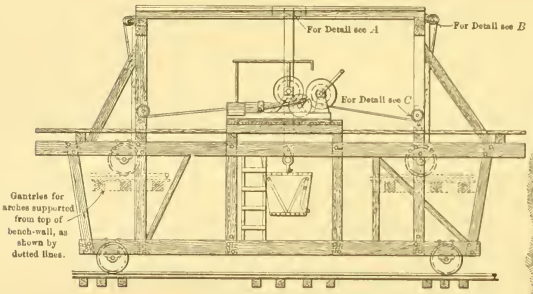
Methods of Handling Concrete in the Tunnels.—The concrete for the floor, ditches, and foundations, was brought into the tunnel in V-shaped steel, dumping cars, and dumped as near as possible to the place it was to occupy.

The concrete for the arches and bench-walls was loaded at the mixers into 1-yd., Stuebner, bottom-dumping buckets which just held a 4-bag batch. These buckets were placed on small flat cars, hauled into the tunnel, placed beneath the traveling gantry, as shown by Fig. 1, Plate XXIV, and hoisted to the platform above.

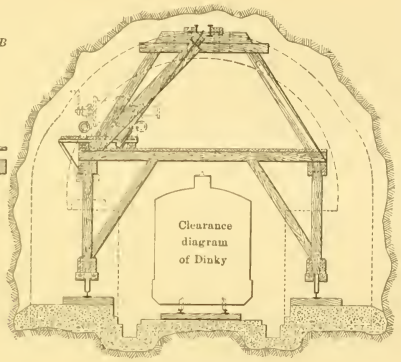
These traveling gantries, the details of which are shown by Fig. 12, consisted essentially of platforms at each end of which an A-frame was erected; the latter supported at their apexes two I-beams, from the lower flanges of which was suspended a traveling block, shown at *A*, Fig. 12, and through which the hoisting rope was rigged. The buckets were hoisted through an opening in the platform and then moved along to where they could be dumped. The platforms were supported on wheels traveling on rails laid on the concrete of the foundation (for the bench-wall gantries) or on top of the bench-wall (for the arch gantries).

Each of the first two of these traveling gantries used was equipped with a belt conveyor working on a cantilever arm, as shown by Figs. 3 and 4, Plate XXI, and Figs. 1 and 2, Plate XXIV. In using these belt conveyors, the concrete was dumped from the Stuebner bucket into a hopper, Fig. 1, Plate XXIV, with an adjustable slot in the bottom, under which the belt ran.

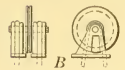
It was the original intention, in designing the conveyor, that the end of the cantilever arm should be swung from one side of the tun-



SECTIONAL ELEVATION.

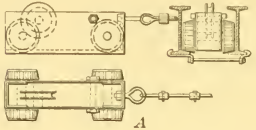


CROSS-SECTION.



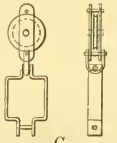
B

DETAIL OF TOP SHEAVE.



A

DETAIL OF TRAVELING BLOCK.



C

DETAIL OF LOWER SHEAVE.

DETAILS OF TRAVELING GANTRY USED IN THE CONSTRUCTION OF THE TUNNEL LINING.

FIG. 12.

nel to the other, and that the traveler should be moved backward or forward, as might be required, and thus deliver the concrete from the end of the belt directly over the place in which it was to be deposited in the bench-walls. As a matter of fact, it was found impractical in operation to move the gantry readily, owing to its great weight, which was supported on only four ordinary car wheels and their bearings, and it was found more convenient to leave the arm in one position near the center, letting the concrete drop on the platform above the bench- or sand-wall forms, whence it could be shoveled into place, than to attempt to move it as had been intended. Both of these difficulties might possibly have been overcome by modifications in the design of the gantry and conveyor, had this method of handling the concrete seemed otherwise desirable.

The principal difficulty with its use, however, was the inability to take care of more than one batch of concrete at a time. When one batch had been dumped into the hopper, a second could not be disposed of until the first had nearly all run through on the belt, and this took from 7 to 20 min., varying with the consistency of the concrete, etc. In a few instances, where there happened to be some fairly dry batches, the concrete could not be started through the slot at all, and had to be shoveled out of the hopper. On the other hand, it is stated that some batches, under favorable conditions, passed through in about 2 min., but this was quite exceptional, and the operation was irregular and uncertain.

Before the final method of handling the concrete was adopted, a trial was made of two forms of cars and buckets, to be used on the top platform, as shown by Figs. 3 and 4, and Plate XXIV. In the method shown by Fig. 3, Plate XXIV, the concrete was hoisted in the regular Stuebner buckets, one of which can be seen suspended in the background of this photograph, and dumped into the car shown, which was mounted so that it could be revolved in a horizontal plane. It was intended to move this car on the tracks to the point at which the concrete was required, and dump it directly through a chute into the bench-walls. This car was abandoned, as there was a great deal of difficulty in turning it when it was loaded, and in several instances it had to be dumped straight ahead in the middle of the platform and the concrete shoveled into the forms. This method was also objectionable when the bucket was dumped, inasmuch as the force of the impact

of a whole batch of concrete dumped from such a height into the forms, not only tended to throw the conduits out of line, and to break them, but also caused considerable strain on the forms.

The bucket shown by Fig. 4, Plate XXIV, was next tried. It had a slanting bottom and a door opening at the side. It was filled at the mixer, came into the tunnel on a small flat car, and was hoisted and placed on a similar car on top, as shown. This bucket was not successful, as its great weight made it difficult to handle, and it generally required a man to shovel the concrete out, which latter, of course, had been pretty well compacted in the bottom of the bucket by its trip from the mixer. All these cars were hauled backward and forward on the top platform by a rope running to the winch on the hoisting engine on the traveling gantry.

Aside from the fact that neither type was a success, neither of these schemes was much improvement over the belt, inasmuch as only one batch could be handled at a time, owing to the necessity of using the engine to haul the cars back and forth on the platform. The final solution was found in the use of the traveling gantry, shown by Fig. 12 and Fig. 1, Plate XXVI, the latter being one of the arch gantries. The gantry used for the bench- and sand-walls was supported on framed bents on wheels running on rails laid on the foundation; that for the arch was the same, except that the high-framed bent was dispensed with, the side-sills resting directly on the journals of wheels traveling on rails on top of the finished bench-wall.

These gantries were used only as a means of hoisting the buckets and moving them along to where they could be dumped directly on the platform, whence the concrete was shoveled into wheel-barrows, which could be dumped directly into the bench-walls; or, in the case of the arches, shoveled from the platform of the gantry to the intermediate platform on the arch ribs, and thence directly into the arch. This use of wheel-barrows, though apparently a somewhat crude method and a retrogression from the use of the belt conveyor, proved very successful, and really involved no more labor than did the conveyors, although this might not have been the case had these latter worked as they were originally designed to.

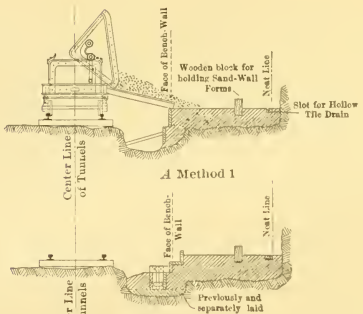
The method finally adopted allowed as many as four buckets to be dumped on the platform on one end of the arch gantry at one time, and eight on one end of that used for the bench-walls, the workmen

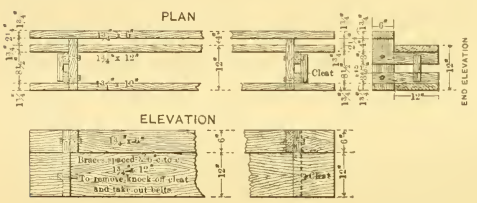
handling about three of these latter into the forms by the time the last of the eight was dumped. It required about 1½ min. to place a car under the gantry, hoist the bucket, dump, close it, and return it to the car below.

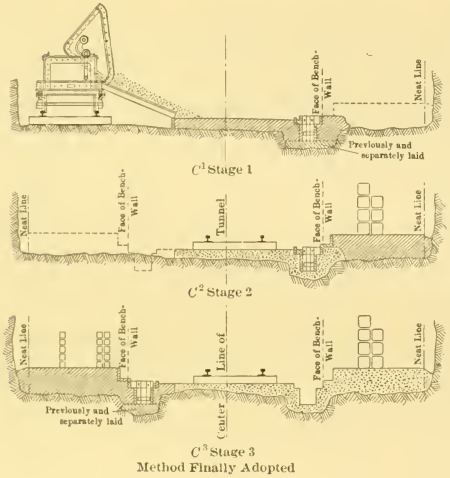
Rock packing was stored at the other end of the platform, for use as required, when it was not handled directly from the end nearest the work. This method allowed the concrete and other materials to be brought in in trains at infrequent intervals, and provided a sufficient supply of material on hand so that the men handling it on top could be kept steadily at work.

Each hoisting engine on these gantries had 7 by 10-in. cylinders, and a double drum; some of them were Lamberts and some Mundys, operated by compressed air.

Ditches, Floor and Foundations.—The first method of building the foundation was that shown by Fig. 13, *A*; no attempt was then made to build the ditch, or floor, the intention being to leave these until the completion of the remainder of the lining. In building the bench-wall on this foundation, however, it was found difficult to secure the bottom of the forms properly (Fig. 2, Plate XXV), so as to prevent any give, as the material under the track was not solid enough to brace against. It was decided, therefore, to build the whole of the ditch (see Fig. 13, *B*) so that the bottom of the forms could be braced against the solid concrete. At the beginning of the work, the face of the bench-wall was built up to the level of the bottom of the conduits with the foundation; if, therefore, in placing the concrete above this level, extreme care were not taken to get a tight fit between the bench-wall form and the lower face, and then to hold it rigidly in place, the result was a rather unsightly horizontal joint high enough to be plainly visible. The position of this joint may be seen in Fig. 2, Plate XXV, which shows the first section of bench-wall built. Several subsequent sections showed an overhang above this joint, amounting in one or two cases to as much as ½ in., due to the fact that the bench-wall form moved or did not fit tightly. This defect was obviated by building the foundations with an offset on the face, shown by Fig. 13, *B*, so that the joint came at the level of the top of the flagging over the ditches, and therefore was almost entirely concealed; at the same time this allowed a sufficient surface, on the plane of the face of the bench-wall, against which the bench-wall forms could be braced and lined up.







PLAN SHOWING VARIOUS METHODS OF BUILDING FLOOR AND FOUNDATION, AND DETAILS OF FORMS

FIG. 13.

The ditch forms were set very carefully to line and grade by the alignment corps, as this formed the starting point of all the rest of the work, the only other thing which was necessary was to give a level at the front end of the bench-wall form, after it was set, for the elevation of the top of the bench, and to check up the stations of the ends of the sections occasionally to see that they were at the even 25-ft. points (that is +08, +33, +58, and +83).

After a short length had been built with the ditches only, it was thought desirable to try and put in the floor as well, so that the whole of the concrete would be put in place as the lining advanced, and leave less cleaning up to be done over the end of a single track, in the restricted spaces between the bench-walls. Fig. 13, *C*, shows the method finally adopted. In this may be seen the three stages in which it was put in, the details of the ditch forms being shown by Fig. 13, *D*.

In that part of the tunnel where sand-walls were built, a hollow tile drain was built into the foundation, as shown in Fig. 13, *A* and *B*, along the foot of the water-proofing and connected at intervals with the drains by 4-in. cast-iron pipes. When the sand-walls and water-proofing were not built, however, the concrete of the foundations was sloped from the neat line back to the rock, as shown by Fig. 13, C^3, so that in case any water found its way down through the rock packing, its tendency would be to flow back against the rock, or to follow the low part of this concrete to 4-in. cast-iron pipes leading to the side ditches, rather than to find its way through the joint between the foundation and the bench-wall and so into the lower duct lines.

Sand-Walls.—The sand-wall forms first used are shown in Fig. 2, Plate XXIV, with a section of the finished sand-wall. As this work was only intended to give a comparatively smooth surface against which to place the water-proofing, no particular care was taken with the surface, except to avoid sharp projections which might cut through the felt and pitch used for this purpose. A rather porous concrete (with all the rock which could be safely embedded in it and have the wall stand) was used, so that it would not act as a dam, but rather tend to allow the water to find its way to the bottom of the tunnel, and so into the drains.

The traveling gantry for placing the concrete in the sand-walls, as first designed, with the belt conveyor, could of course only deliver the concrete at one end. Before setting the forms for a new section, it

was necessary, therefore, to move the gantry ahead, before the cross-bracing between the tops of the forms, which also held the top platform, could be placed in position. Fig. 2, Plate XXIV, shows the end of the conveyor over the top of the cross-braces. In order to hold the bottom of these forms, small wooden blocks were embedded in the foundation concrete, against which they could be wedged, as shown by Fig. 13, *A*; these blocks were cut out after the sand-wall had been built.

After the forms had been filled, the conveyor could not be moved back to the bench-wall until the concrete had set sufficiently so that these cross-braces could be removed, and, on account of the overhang at the top, the set had to be fairly good in order to prevent this overhang from breaking off. This arrangement, therefore, for placing the concrete was found to be impractical, if the proposed schedule of a section of bench-wall and a section of sand-wall to be built on alternate days, was to be carried out. In a few instances, where the sand-wall was finished fairly early in the afternoon, the forms were released next morning, and the conveyor was moved back, but, even then, 2 or 3 hours at least were lost at the beginning of the shift. The conveyor, however, was abandoned, for the reasons previously given, and the traveling gantry was rearranged to allow concrete to be delivered at either end; it was then only necessary to move it backward and forward between the bench- and sand-wall forms instead of through these forms. This permitted the construction of the much more substantial type of forms shown by Fig. 14.

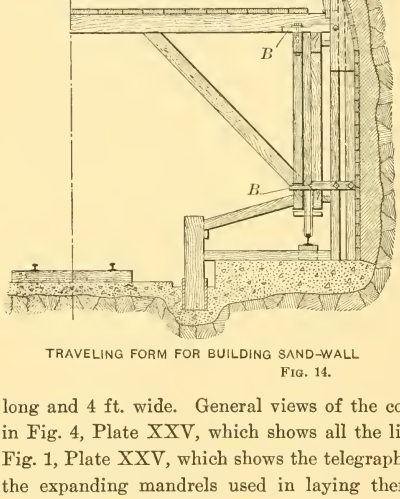
After being moved ahead on the track on top of the foundation, the form was first blocked up to grade, and then adjusted to line by the screws and slotted cleats shown at *B*, Fig. 14, after which it was secured by the braces from the ditches, as shown. The face lagging was placed in separate pieces and held against the uprights by lightly nailing every third or fourth piece; the whole was removed each time the form was moved, and built up again as the concrete was placed.

Considerable care was taken to slope the top of the sand-wall back toward the rock, as shown by Fig. 14, and to allow free drainage along the top (which ran parallel to the grade of the tunnel) to the 4-in. cast-iron drain pipes which carried the water from the rock packing above the arch to the drains beneath the track.

Sand-walls were built for a length of about 1 100 ft. in each tunnel at the Weehawken end, and about 700 ft. in each tunnel at the western

end, the remainder of the work, with the exception of a few short stretches, not being considered wet enough to require water-proofing.

Conduits.—The arrangement of the conduit lines is shown in the general cross-section.* On the core-wall side there are 48 lines for telegraph and telephone cables, built of 4-way multiple conduit, each piece of which is 3 ft. long and about 10 in. square outside. On the other side there are the high- and low-tension lines, built of single conduit 18 in. long and a little more than 5 in. square outside. Manholes or splicing chambers are built every 400 ft., and are about 8 ft.



TRAVELING FORM FOR BUILDING SAND-WALL

DETAIL SHOWING METHOD OF HANGING WATER-PROOFING FROM TOP OF SAND-WALL

FIG. 14.

long and 4 ft. wide. General views of the conduits as built are shown in Fig. 4, Plate XXV, which shows all the lines in one tunnel, and in Fig. 1, Plate XXV, which shows the telegraph and telephone lines, with the expanding mandrels used in laying them.

In attempting to plan the work of placing the lining, two methods of building the bench-wall were considered. One was to build the wall in longitudinal sections, each section separated by a line of ducts; and the other was to attempt to build the wall in the manner called for by the specifications, which required the concrete to be carried up in layers as the conduits were laid. In this latter method, it was

* Plate VIII in the paper by Mr. Jacobs.

FIG. 1.

FIG. 2.

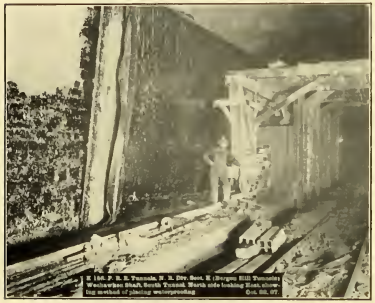


FIG. 3.

FIG. 4.

proposed to bond the concrete together with the forked bonds, the details of which are shown by Fig. 15, *A*, but, as it might have been impractical to use these if the wall had been built in sections, provision was made in the contract to place expanded metal, as shown by Fig. 15, *B*, if this was thought advisable. The method of construction necessary, if the wall had been built in sections, is shown graphically by the five sketches, Fig. 15, *B*, 1, 2, 3, 4, and 5.

The form and details of the expanding mandrel which was finally designed to meet the conditions, and proved so satisfactory in every way, are shown by Fig. 15, *C*. The mandrel consisted of two triangular pieces of hard pine, separated by wedges attached to one piece which fitted into slots in the other; these, when expanded, practically filled the whole of the inside of the ducts. One of these mandrels was placed in each line of single ducts and two in each 4-way duct, placed diagonally, as shown in Fig. 1, Plate XXV. This required 60 mandrels at each working point, or 240 for the whole work. The mandrels were 35 ft. long, so that they easily covered the whole of a 25-ft. section, projected sufficiently far back into the previously finished work to assure the continuity of the alignment, and allowed the ends to be racked out at the forward end to secure proper breaks between the joints.

In laying the single conduits, as a rule, the (collapsed) mandrels were pulled ahead from the previous section as each line was laid, and the conduits were strung on it until the whole length was completed; the conduits were then pushed up tight together, so as to close the joints as tightly as possible, and then the mandrel was expanded. The conduits were thus held firmly in position, and the forward end of the line was lifted slightly so that the wraps could be placed around the joints. The 4-way conduits were generally laid in the ordinary way, except that no laying mandrel was necessary. One dowel was used between each of the pieces of conduit, at the center, and the joints were wrapped. When a line was finished, two mandrels were placed diagonally in each line and expanded simultaneously, so that any inequalities in the ducts themselves were divided as far as possible. In connection with the use of these mandrels, one of the points which was most carefully watched was that they projected back into the last completed section, thus insuring the continuity of the alignment.

It was originally intended to wrap the joints of the 4-way ducts

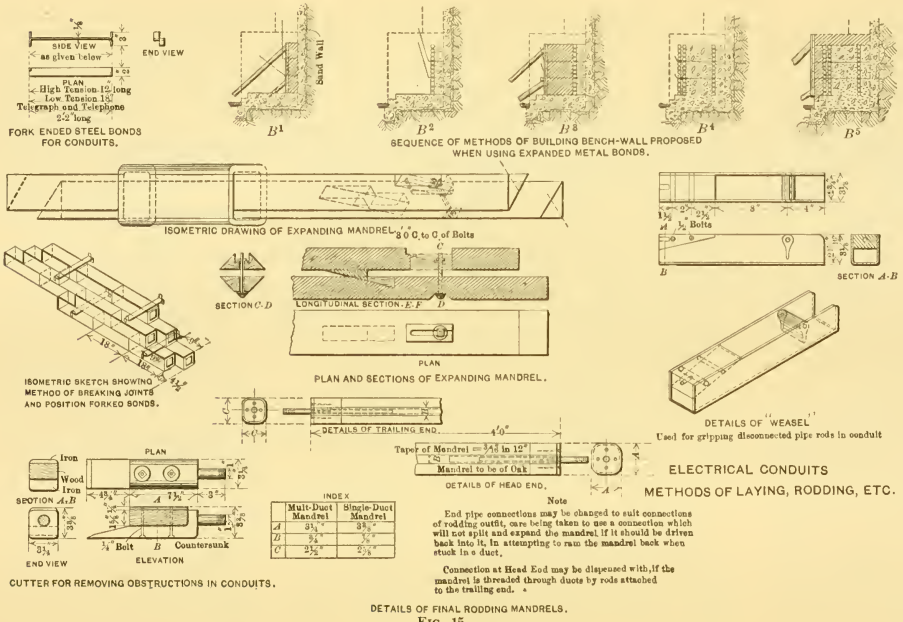
only, but it was found to be impractical to keep the grout from the wet concrete entirely out of the single ducts, and, after a short trial, it was decided to wrap these also. The expanding mandrel kept out a great deal of the cement, and, in the sections laid without wraps, the only difficulty from this cause seemed to be that a slight film of grout, from $\frac{1}{16}$ to $\frac{1}{8}$ in. thick, was deposited on the bottom of the inside of the ducts at some places, and although this was not considered a serious defect, it was thought that the slight extra cost of placing the wraps would undoubtedly be justified by the practically perfect results obtained by using them.

Considerable attention was given to breaking the joints of the ducts properly, so as to maintain throughout the conduit lines the greatest break possible. The joints in each superimposed line were broken at half the length of the individual pieces of conduit, the joints in lines in the same horizontal plane being broken at one-quarter the length, thus preventing any joints from touching one another either at the sides or corners, which tended to prevent a burn-out on one line from being communicated to another. There was some little difficulty at first in maintaining the breaks, owing to slight variations in the lengths of the conduit, but after a very short time both the workmen and the inspectors became very expert at this and in the proper use of short lengths to maintain the spacing; after the first few weeks there was little if any difficulty in attaining at all times almost perfect results. The method of making the breaks is shown in the photographs and by the isometric sketch at *F*, Fig. 15.

All the conduits used on this work were furnished by the Great Eastern Clay Company, and were made at its factory at South River, N. J., where they were inspected before shipment.

The mandrel used in the final rodding was made as shown at *G*, Fig. 15, the larger size being used for all lines. The rods for pushing it through the conduit lines were made of 6½-ft. lengths of ordinary 1-in. wrought-iron pipe with extra long (3-in.) couplings. The lines were rodded in both directions from alternate manholes, thus avoiding uncoupling the rods and allowing every pull to be effective in pushing the mandrel through the ducts.

Wooden rods were used at first, but proved entirely too light, as the mandrels used were a close fit, and it required considerable effort to push them through 400 ft. of conduit. Iron pipe with ordinary couplings



	Multi-Duct Mandrel	Single-Duct Mandrel
A	3½"	3⅝"
B	3¼"	3"
C	2½"	2⅞"

FIG. 15.

was next tried, but the couplings broke quite often, as the threads became worn in uncoupling the sections to move the rods from one line to another, and the break was generally inside a duct line. The long couplings were finally adopted, and a set of rods was put in each line, that is, six sets in all, so that when coupled up they remained in the line until it was finished. The expense of the extra quantity of pipe thus required was more than offset by the decreased labor cost.

It was thought necessary at first to run a cutter, Fig. 15, *E*, through the conduits ahead of the final rodding mandrel, but this was soon found to be unnecessary except in a very few instances, and, after a short experience, the cutter was only used at places where an obstruction was encountered by the mandrel.

At such times as the pipe became uncoupled inside the duct line, the part remaining inside was recovered by the use of the tool shown at *D*, Fig. 15, called a "weasel." In two instances, the mandrel became stuck in such a manner that the duct line had to be cut into in order to take it out.

The best day's work of the rodding gang (1 foreman and 4 men) was 20 400 duct ft. of the 4-way conduit in the telegraph and telephone line, and 19 200 duct ft. of single conduit on the low-tension line, an average day's work under ordinary conditions being about 10 000 duct ft. The cost, including labor, material, and all tools, for rodding for the whole work was slightly less than 0.2 cent per duct ft. The average cost of the single conduit was about 0.25 cents per ft., and of the 4-way, 0.15 cents per ft. About 10% of the conduit lines were rodded twice, owing to partial sections having been rodded once before completion. The best continuous work on rodding was done between October 22d and 29th, 1908, when in 7 working days, 105 600 duct ft. were rodded, an average of a little more than 15 000 ft. per day.

Bench-walls.—The original design for the tunnels provided for the construction of a brick arch above a point 22° above the springing line, that is, the part above the side-walls (Fig. 10). It was thought desirable, therefore, in designing the bench-wall forms, to provide for placing the concrete in the side-walls and bench-walls at one operation. These forms, as first designed, are shown by Fig. 2, Plate XXV, and the details in Fig. 16, *A* and *A'*; they were built of steel, the facing plates being $\frac{5}{16}$ in. thick, in pieces 4 ft. 6 in. wide, and in length about 6 in. more than the height of the bench-wall.

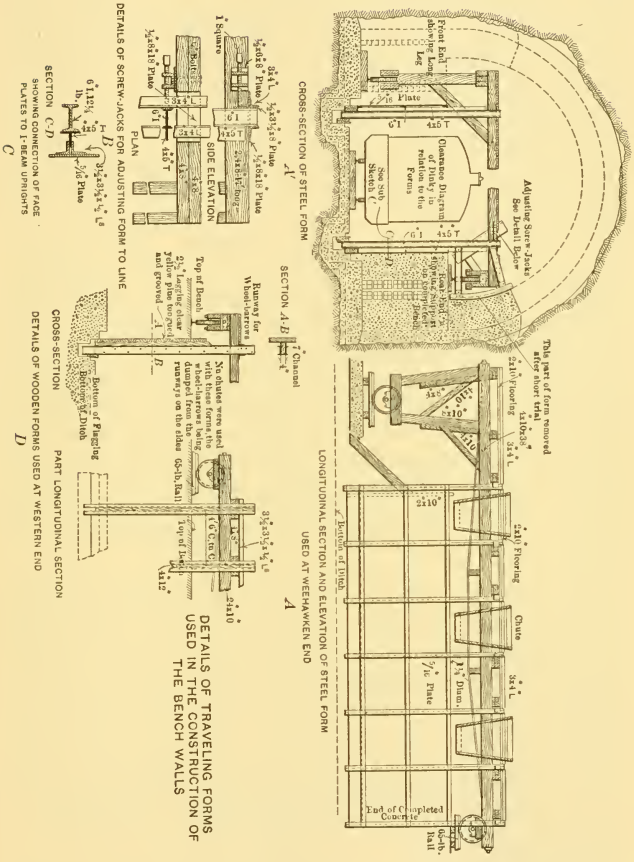

CROSS-SECTION OF STEEL FORM
A
Front End of Long Leg
Adjusting Screw-Jacks See Detail Below
Clearance Diagram of Dinky in relation to the Forms
See Sub Sketch C
This part of form removed after short trial
LONGITUDINAL SECTION AND ELEVATION OF STEEL FORM USED AT WEEHAWKEN END
A
Bottom of Ditch
Chute
End of Completed Concrete
SECTION A-B
Runway for Wheel-barrows
Top of Bench
Bottom of Flagging
Bottom of Ditch
CROSS-SECTION
PART LONGITUDINAL SECTION
DETAILS OF WOODEN FORMS USED AT WESTERN END
D
DETAILS OF TRAVELING FORMS USED IN THE CONSTRUCTION OF THE BENCH WALLS
SIDE ELEVATION
PLAN
DETAILS OF SCREW-JACKS FOR ADJUSTING FORM TO LINE
B
SECTION C-D
SHOWING CONNECTION OF FACE PLATES TO I-BEAM UPRIGHTS
C

FIG. 16.

The design was controlled very largely by the necessity of providing the requisite clearance for the locomotives and muck cars, and the principal feature was the support of the forms on two trusses, one at either side, the front ends of which were supported from the foundation on a long leg, as shown in Fig. 3, Plate XXV, and the rear ends directly on the journal-boxes of wheels traveling on a rail on the top of the finished bench, as shown in Fig. 2, Plate XXV.

Although it had been decided to substitute concrete for brick in the arch before any of the lining was actually placed, two sets of forms for the Weehawken end had already been ordered and delivered, so it was decided to use them as designed, and place the side-wall with the bench.

The forms were designed so that 30-ft. lengths could be built, and this was done at the start, but owing to the occurrence of the refuge niches, ladders, etc., at 25-ft. intervals, it was soon seen that it would be advisable to build the bench-wall in sections of that length (25 ft.), or multiples of it, and as the clearance conditions seemed to preclude the possibility of making the forms 50 ft. long, 25 ft. was adopted. This permitted the removal of one of the panels, 4 ft. 6 in. wide, and at the same time it was decided to remove the side-wall forms. This decreased the load on the trusses considerably, but being still a trifle weak, they were strengthened by the substitution of $1\frac{1}{4}$-in. truss rods instead of the $\frac{3}{4}$-in. rods used originally. The top platform and the cross-bracing were also stiffened a little and tightened up to prevent racking.

The construction of the side-walls in conjunction with the bench-wall was abandoned for three reasons: First, it was found that there would be a much more even distribution of the work by including the side-wall with the arch rather than with the bench; second, there was difficulty in getting a good finish for the top of the bench-wall, as of course a top form for the latter had to be placed to prevent the concrete from squeezing up when the side-wall was built above it, which prevented troweling; the third reason was the weakness of the whole form as designed, and the increasing difficulty of adjusting it to line as the work progressed, the principal difficulty being with the curved side-wall forms.

The bench-wall forms were set in position, after they had been moved ahead, by first blocking the bottom against the face of the

foundation, as shown by Fig. 13. As previously noted, this foundation face had been built very carefully to line. The back end of the form, of course, was blocked tightly against the end of the previously finished section, and the top was made plumb by the adjusting screw-jacks shown in Fig. 16, *B*. At first these screws were $\frac{3}{4}$-in., but they were afterward changed to $1\frac{1}{4}$-in. The only points which it was necessary for the alignment corps to give in setting these forms was a grade at each of the front ends for the top of the finished bench.

The steel face forms in both tunnels gave excellent results, as far as smoothness of finish was concerned, but, owing to the imperviousness of the steel, small air holes were formed in the surface, though not in sufficient numbers or size to cause trouble or disfigure the work in any way.

The design of the bench-wall forms used at the western end, where this differs from the steel form, is shown by Fig. 16, *D*. The principal features in which they differed from those used at the Weehawken end was in the substitution of $2\frac{1}{2}$-in. tongued and grooved hard pine for the face. This timber was of the very best quality obtainable, each piece being especially selected and as nearly clear and free from knots or other defects as it was possible to get it. The edges of each piece were planed at the back so as to insure a tight joint on the face, and all joints were shellacked. These forms were used, without renewal of the face timber and with only two planings, for a length of 2 500 ft., or 100 separate sections, and gave good satisfaction.

In order to obtain a surface to which the face lagging could be fastened, wooden uprights were used and were reinforced on either side by light channels bolted together through the timber, in place of the I-beams used on the steel forms. The lagging was nailed to these uprights by 6-in. wire nails driven through the top edges of each piece as it was placed in position, thus leaving the surface entirely clear and free from any marks or nail holes, and in condition for planing when this became necessary. Runways for wheeling the concrete were built one either side over the bench-walls instead of having a center platform with chutes, as was used at Weehawken.

When the original lagging had become too much worn for further use, it was resurfaced with strips of $\frac{7}{8}$ by $2\frac{1}{2}$-in., clear, tongued and grooved, hard pine, placed vertically, which did fairly well and lasted to the end (about 1 000 ft.), although it was not altogether satis-

factory, and the last eight or ten sections built had to be rubbed down with a wooden float in order to obtain a suitable finish.

In designing the forms for all exposed surfaces in the tunnels, it was the desire of the contractors to obtain directly from them a surface which would be satifactory to the engineers without further finishing than the patching of minor defects. In this they were generally quite successful, and excellent results were obtained, as shown in the view of the finished tunnel, Fig. 2, Plate XXVII. The surface of the bench-walls was obtained solely by spading the face with a flat spade as the work progressed. No after treatment was resorted to, except for the few sections where the forms became worn. The top of the bench-wall was finished with a float about 2 or 3 hours after the concrete was placed.

When the work was well organized, a bench-wall was built at each end each day, one day in the North Tunnel, and the following day in the South. During the time sand-walls were being built, a sand-wall and bench-wall were built on alternate days in each tunnel, care being taken that when a bench-wall was being built in one tunnel, the sand-wall was being built in the other, this being necessary in order to equalize the work of the night gang and the conduit layers as well as the transportation.

The conduit layers on the day shift, two or three men and a foreman, required about 2 hours in the forenoon and 1 hour in the afternoon to lay their portion of the conduits, and usually finished this work by 3 P. M. At other times during the shift they were utilized at those points where rock packing was heaviest, and when the packing was brought in in the large cars, as shown in Fig. 1, Plate XXVI, these men helped unload it so that the track could be cleared as soon as possible. When water-proofing was to be done, the number of men in this gang was increased, so as to enable them to do that work also.

A gang of four rough carpenters and a foreman was employed on the day shift; they moved and set the bench-wall forms or sand-wall forms, as the case might be, and moved the traveling gantry into position. This was done in the afternoon, and required about 3 hours. They also took out, cleaned, repaired, and set all ditch forms, all passenger forms, circuit-breaker forms, and did all other repair work. The ladder forms, the refuge-niche forms, and overhead conductor

Fig. 1.

Fig. 3.

Fig. 2.

Fig. 4.

pocket forms were attended to by one man, who set, removed, cleaned, and repaired them. The carpenters on the night shift set the arch centers and gantries, also the manhole forms when needed. The conduit layers on the night shift laid up half the 4-way conduits (3-high) and one-third of the single ducts (4-high). This one gang laid the conduits in two sections of bench-wall each night, that is, one section at Weehawken and the other at the western end.

In concreting the bench-walls, the concrete was first placed on the side containing the single conduit until it reached the top of the four tiers laid, then the concrete gang was turned over to the side with the 4-way conduits while four more tiers of single conduits were laid, the work thus progressing, the conduits being laid on one side while concrete was placed on the other. On the side of the 4-way conduits the concrete was built in two layers while that on the side of the single ducts was built in three; the interval between the different layers was not sufficiently long to prevent a complete bond being obtained, and there were only one or two instances where there was any mark on the face to indicate a break.

After the work had been in progress some time, it was found to be quite feasible to build all the 4-way conduits at night and half the single conduits, that is, 6 ducts high, as the mandrels proved amply sufficient to hold them in place; in fact, had it been necessary, the writer has no doubt that all the ducts might have been laid and held in place with very little extra precaution, by the use of the expanding mandrels, as described under the head of conduit laying. A V-shaped joint about ½ in. deep was made between each section of bench-wall so that the expansion cracks would follow this joint rather than show irregularly on the face. These joints divided the face into the even 25-ft. panels, and were very effectual in concealing what few cracks there were.

After the construction of the sand-walls was discontinued, the space behind the bench-walls, between the neat line and the rock, was filled with rock packing, which was generally built, part way up at least, as a dry wall ahead of the construction of the bench-wall, or it was put in place simultaneously with the concrete, care being taken to keep it as free as possible for the drainage of any water there might be. Toward the latter part of the work, owing to the difficulty of getting sufficient rock packing during the day, a rough back form

for the bench-wall was built at the neat line, in places where the section was at all large, and the space was filled with rock afterward, generally at night or on Sundays.

In the sections where water-proofing was required, where no sand-wall was built, the rock was taken out for 2 ft. outside the neat line, if the excavation was not already that far out (at the expense of the contractors, who preferred to do this rather than build the sand-walls for the short sections required), so that there would be sufficient room for placing the water-proofing on the back of the bench-walls, as shown by Fig. 18, *E*. The water-proofing of these sections was left until just before the arch was to be built, and after being placed it was protected by a single row of brick laid on edge before the rock packing was filled in.

Arches.—The centering used for the arches is shown very clearly in Fig. 4, Plate XXV, which is a view of the back end of the first section built at Weehawken. In this part of the tunnel, the lower part of the arch, about 5 ft. above the bench-wall, was built first, as previously referred to, but the centers, as will be seen, were built so that they could be used for the whole of the arch. The forward bulkhead, and the shoveling platform on a section being built, are shown in Fig. 3, Plate XXVI.

The front bulkheads used were made in nine sections, bolted to a $2\frac{1}{2}$ by $2\frac{1}{2}$-in. angle bent to the radius of the arch, as shown in Fig. 3, Plate XXVI, and fitting on the end of the lagging; when set they were braced partly against the rock of the roof and partly against the gantry. After the ribs and part of the lagging had been set by the night gang for a fresh section of arch, the braces holding the bulkheads were knocked out, the concrete placed during the day having set sufficiently by this time; the whole of the bulkhead was then easily moved ahead, sliding along the lagging to the forward end, and made ready for the next day's work. The middle section at the top was taken out temporarily, to facilitate working at the sides, until it was needed.

The traveling gantry used in handling the concrete for the arch is shown in Fig. 1, Plate XXVI, which also shows the form for the circuit-breaker chamber, and a car of rock packing on the track beneath.

The arches were built in 10-ft. sections, the ribs being spaced 5 ft. apart, the end ribs of each section supporting the end of the lagging

on two adjoining sections. Five sets of lagging and ten ribs were used at each place where the arch was being built, thus giving each section practically 4 days' set before removing the centers. Probably in the greater part of the work the centers could have been removed in from 40 to 48 hours after the concrete had been placed, but 3 days was considered the least time which would certainly be safe at all times, and the contractors thought that the very slight additional expense involved in leaving the centers up 4 days was more than warranted by the additional feeling of security.

The lagging was made from 3 by 6-in. clear, hard pine, 10 ft. long, dressed to about 2½ in. in thickness, about 5½ in. in width, and the sides to radial lines. As it was placed, every third or fourth piece was lightly nailed to the ribs; when the latter were released and taken down, the nails pulled out, and the lagging was left in place until one piece was pried out, allowing the others to fall. A light **A**-frame, about 8 ft. long, spanning the bench-walls, was placed below, in order to break the fall and allow the lagging to slide to the top of the bench-walls rather than fall to the track beneath.

Cross-passages between the two tunnels were built every 300 ft., their form being shown on Plate VIII of the paper by Mr. Jacobs. There were two circuit-breaker chambers, one at Station 286 and the other at Station 310. Steel doors are provided so that all the openings between the two tunnels can be closed. At Station 294+24, the core-wall broke through for a length of about 40 ft., and instead of filling this in, a storage chamber 34 ft. long and 11 ft. wide, inside, was built there, the form for which is shown in Fig. 2, Plate XXVI. This photograph, as well as Fig. 1, Plate XXVI, a form for a circuit-breaker chamber, shows the method of setting the steel doors in the forms, so that they were built into the concrete instead of being fastened in with expansion bolts afterward, thus showing a perfect fit and a much neater job.

During construction the arches in each tunnel were kept even with each other, so that when the cross-passages were reached, they, and the sections of arch which they joined, could be completed at one operation.

By the methods used on this work, one section of arch was easily built in a shift, so that the monolithic construction of each section was easily secured, and concrete, as wet as it was possible to handle with

shovels, could be used for all except the last 5 ft. or so at the top, thus getting a structure which was as nearly impervious as possible under the circumstances.

The gangs placing the arches were paid over-time when they were required to work after 6 o'clock to finish their section, which was generally only necessary when the quantity of rock packing to be placed was very large. If they finished their section before 6 o'clock, however, they were allowed to quit when this was done, and were given a full day's pay. The difference in time, when there was any, was usually due to the greater or less quantity of rock packing, as the excavation varied from the standard section line.

In building the arches, the night gang set the two ribs (one at the center and one at the forward end of the section to be built), placed the lagging on the sides, 4 or 5 ft. high, built the shoveling platform on the horizontal cross-braces of the ribs, and placed the traveling gantry in position for use. The forward end of the gantry (that is, the end farthest from the arch being built), as shown in Fig. 1, Plate XXVI, was loaded with rock packing to be used as required. As the concrete was brought into the tunnel it was hoisted and dumped on the end of the gantry next the arch, and shoveled from there to the platform on the ribs and from there into place. The rock packing brought in during the day was dumped on the front or back end of the gantry, as was most convenient, and handled into the work in the intervals between batches of concrete. The concrete and rock packing, with the back-lagging and water-proofing, where these were used, were placed simultaneously, or nearly so, and brought up the sides together until the key was reached; the latter was then worked from the back toward the front. The key was usually made about 5 ft. wide, the lagging for this width was made 5 ft. long and put up in two sections. It was found to be more convenient to have the key of this width than narrower.

The method used in making the closures where two sections of the arch came together is shown by Fig. 17.

Water-proofing.—As already pointed out, the original design for the lining of these tunnels provided for a brick arch. It was intended to cover this arch with water-proofing, this latter extending over the whole of the roof and down the sides as far as the bottom of the conduit lines. The water-proofing was to be placed against the sand-

walls on the sides, up to the top of the side walls, Figs. 10 and 14. Over the arch, after being placed, it was to be protected by an armor course of brick, laid flat, the space between the brick and the excavation, which was required to be not less than 4 in. (and, as a matter of fact, was actually a great deal more), being filled with rock packing. Besides filling the space, this latter was designed to allow any water from the roof of the tunnel to find its way easily to the top of the

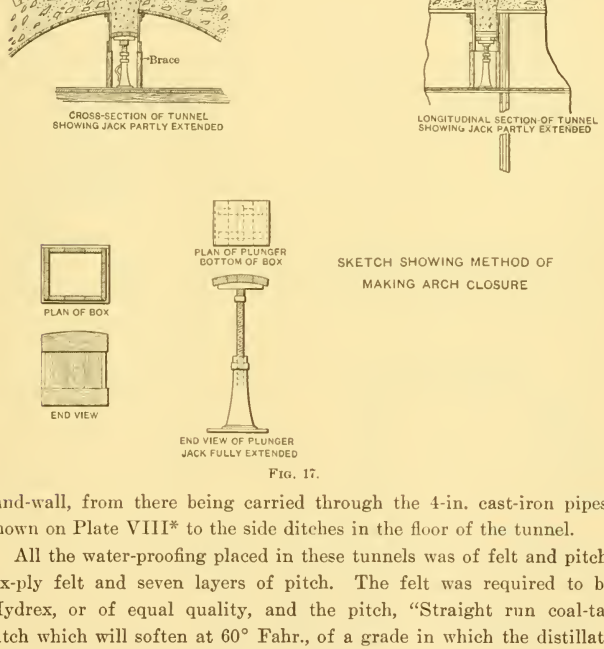


FIG. 17.

sand-wall, from there being carried through the 4-in. cast-iron pipes, shown on Plate VIII* to the side ditches in the floor of the tunnel.

All the water-proofing placed in these tunnels was of felt and pitch, six-ply felt and seven layers of pitch. The felt was required to be Hydrex, or of equal quality, and the pitch, "Straight run coal-tar pitch which will soften at 60° Fahr., of a grade in which the distillate oils will have a specific gravity of 1.05."

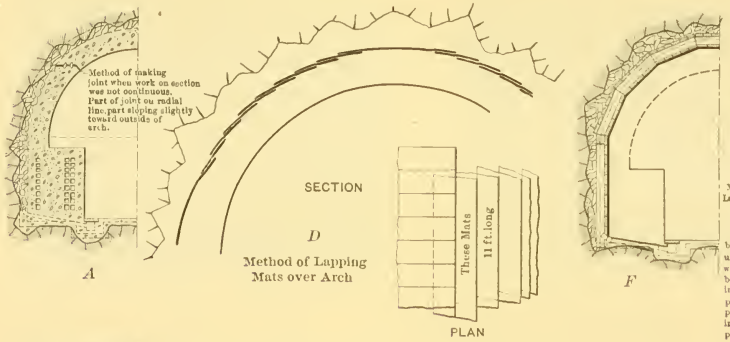
In addition to tests as to the above qualities, the pitch was analyzed

*Of the paper by Mr. Jacobs.

to determine the amount of free carbon it contained, and was not accepted if this fell below 20 per cent.

It was considered quite important that there should be absolutely free drainage on the outer side of the lining, so that there would be no chance for any water to acquire a head. More than three-quarters of the length of these tunnels is below the level of mean high water, and while it was hardly expected that there would be any direct connection between the water in the Hudson River and the ground-water of the section penetrated, it was thought wise to provide ample drainage.

Before the lining was started, however, the excavation had progressed sufficiently to show that the tunnels, while very wet in places, and varying from that to quite damp, would be, on the whole, much dryer than had been anticipated. It was then decided to substitute concrete for the brick in the arch and omit the water-proofing over the top, except at places where water came into the tunnels in sufficiently large quantities to form practically a continuous stream. Three general types of construction for the arch were decided on, as shown in Fig. 18. The first, as shown at *A*, was to be used where the tunnel was quite dry. In this type, the sand-wall was omitted entirely, and the concrete and rock packing were built up together, the rock packing impinging to a certain extent on the concrete, and the concrete squeezing somewhat into the rock packing, as shown by Fig. 4, Plate XXV. The section shown at *B* was used where the tunnels were damp, or where there were slight droppers not forming a continuous stream. The back lagging, of 1-in. boards, which was left in place, provided a practically smooth outer surface on the concrete arch, and allowing the concrete and rock packing to be built almost simultaneously. It was considered that the free drainage through the rock packing, the surface of the boards, and the smooth outer surface of the concrete in the arch would allow the comparatively small quantity of water in these parts of the tunnel to find its way to the sides, and thence to the ditches at the bottom, rather than to percolate through the concrete, and this proved to be very generally the case, as is shown by the dry condition of the tunnel as built. The back lagging was used over the arch, both where the sand-wall was built and where it was omitted, as well as being placed over the water-proofing of the arch as an armor course where water-proofing was required. Where the sand-



DETAILS OF WATER-PROOFING

One layer of felt with 4" overlap to be nailed to lagging of inch boards, using tin washers on nails over the whole of the intrados of the arch before starting any concrete or placing any of the permanent felt and pitch water-proofing. The water-proofing over the arch can be laid in mats of three thicknesses of felt properly joined together with pitch made as shown diagrammatically at "x"

Each of these mats of three-ply felt will be overlapped half the width of the mat, as shown diagrammatically at "y"

VARIOUS TYPES OF ARCHES, AND WATER-PROOFING USED.

FIG. 18.

walls were built and water-proofed, and where the water-proofing was not carried over the arch, the water-proofing was turned in at the top, as shown at *C*, Fig. 18.

The third method provided for water-proofing the whole of the arch, and was the same as *B* except for the addition of the water-proofing inside the back lagging. In placing this water-proofing, the felt was cut in strips about 11 ft. long (about 1 ft. longer than the length of a section of arch), and six thicknesses were cemented together with hot pitch. These mats were then laid shingle-fashion, as shown at *D*, Fig. 18, up the sides of the arch until a space about 5 ft. wide remained at the crown; shorter mats were then brought out over this, laying them perpendicular to the axis of the tunnel. Care was taken in making all laps, irrespective of the direction in which the arch was built, so that they would lay with the grade, that is, so that the water would tend to flow over the edges of the laps rather than against them.

Most of the wet sections of the tunnel were at the ends, where sand-walls had been built for the purpose of providing a smooth surface against which the water-proofing was to be placed; there were several wet places at isolated points in the tunnels, however, and, in order to avoid building sand-walls at these points, the method shown at *E*, Fig. 18, was adopted. This involved a slightly larger excavation, 2 ft. outside of the neat line, up to the height of the top of the bench, where there was not already that much room. The bench-wall was built with a back form on the neat line, the water-proofing was placed as shown, protected by an armor course of brick, and then continued over the arch when this latter was built. The excavation and refilling with rock packing were done at the contractor's expense, which he was willing to assume rather than build these short sections of sand-wall.

The method of water-proofing that part of the timbered section which was very wet, is shown at *F*, Fig. 18, and in Fig. 4, Plate XXVI, and Fig. 1, Plate XXVII. A lagging of 1-in. boards was nailed up the sides and to the soffit of the segmental timbering, all the spaces outside of this lagging being carefully filled with rock packing. Before starting any concrete work, a single thickness of water-proofing felt was nailed to the inner side of the lagging, which not only served to protect the finished surfaces of the concrete from the

FIG. 1.

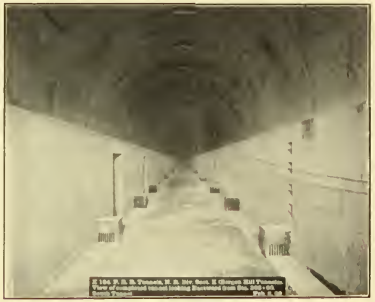


FIG. 2.

FIG. 3.

FIG. 4.

water which fell copiously from the roof, but also provided a comparatively dry surface to which the regular six-ply water-proofing could be cemented with pitch and held in position, while the concrete was placed against it.

In placing the water-proofing in this section on the sides, the strips of felt were placed vertically, nailed at the top to the wall-plate, to support their weight, and lapped and cemented with pitch to the sides as on the sand-walls, except that there was no trouble from the overhang. After the bench-wall had been built, the felt was cut just below the nails and about 2 ft. above the top of the bench, so that the mats which were placed over the arch could be inserted behind it. The roof was covered with three-ply mats and lapped over a little more than half, as shown diagrammatically on the drawing.

When the upper part of the arch was reached, where the cementing strength of the pitch was not sufficient to hold the felt in place, the mats were braced temporarily from the centering, as shown by Fig. 1, Plate XXVII, until the concrete could be packed against it.

Where the water-proofing was placed against the sand-wall, the method of securing the sheets at the top is shown in the small sketch on Fig. 14 and by Figs. 3 and 4, Plate XXIV. Fig. 3, Plate XXV, shows the laps of the sheets and the method of hanging. At the start an attempt was made to stick the water-proofing to the sand-wall, but this could not be done on account of its dampness and the overhang at the top.

The sand-wall water-proofing was kept about 35 ft. ahead of the finished bench-wall, as shown by Fig. 3, Plate XXV. As the bench-wall form was moved ahead and set, the mat was braced back against the sand-wall from the forms at a point just above the top of the finished bench, care being taken to avoid wrinkles, as, if these were once formed, it was practically impossible to straighten them out.

The completion of the bench-wall left the upper part of this water-proofing stretched taut across the curved top of the sand-wall, forming a chord of the arc. As the arch was built up, the top was gradually slackened so as to allow the concrete to press the mat back into place until the top of the sand-wall was reached, when the end was turned in, as shown at *C*, Fig. 18, or the water-proofing was continued over the arch, if that was necessary.

The desire to obtain a dry tunnel, and the methods adopted to

secure it, were responsible in a great measure for the decision to build the arch in short lengths, as well as the reasons given under the head of arches. Had the tunnels been dry throughout, the method shown at *A*, Fig. 18, could have been used exclusively, and, except for the fact that monolithic concrete might not have been obtained, there would have been no objection to building longer lengths.

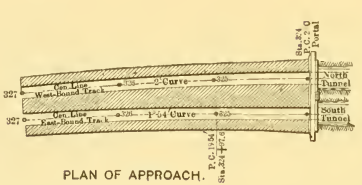
The quantity of water reaching the tunnel drains and flowing out of their lower ends after the completion of the lining was about 100 000 gal. per day, or 75 gal. per min.; of this it is estimated that considerably less than 1% comes through the lining in the form of leaks. The very general distribution of this water over the roof is indicated by the fact that, during the excavation of the first 1 000 ft. of both tunnels from the Weehawken end, oilskins had to be provided for the laborers to induce them to work at all. The success, therefore, of the rock packing as a means of diverting this water to the side drains, is shown, especially in view of the fact that, excluding the cut-and-cover section, only 10% of the length of the arch, 1 189 ft., was water-proofed.

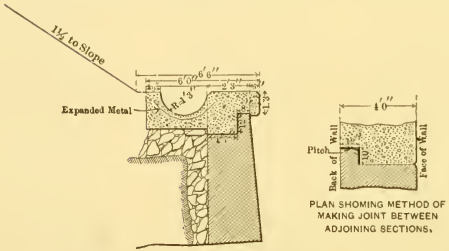
Considerable care was taken to make all joints in the concrete which were in such a position that water might follow through them to the inside of the tunnel lining, in such a manner that they would slope outward toward the rock. The top of the sand-wall is shown by Figs. 14 and 18. The slope of the back of the foundation may be noted in Fig. 18, and the method of making the joint in the arch, in the few instances where a section was not completed at one operation, is shown at *A*, Fig. 18. These joints in the arch were not allowed to be made above a point 60° above the springing line.

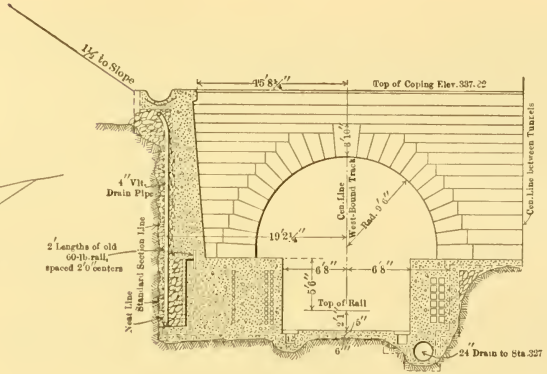
Hackensack Portal and Approach.

The approach cut at the western end is 300 ft. long, the alignment being a 2° curve, as shown in Fig. 19. The bench-walls and conduit lines built throughout the length of the tunnels are extended through the approach cut, the top of the former gradually sloping from the portal to the mouth of the cut, where they are just level with the top of the rail, the conduits also being depressed to the same relative position with the tops of the benches.

The top of the rock at the mouth of the cut, Station 327, was from 4 to 6 ft. below the top of the rail, and gradually rose through







BERGEN HILL TUNNELS.

Hackensack Portal and Approach.

SECTIONS AND ELEVATIONS.

FIG. 19.

the approach until at the portal it was about 6 or 8 ft. above the roof of the tunnel. The rock was covered with hardpan. A profile of this part of the work is shown on Fig. 19. The rock throughout the approach was water-bearing to a considerable extent, and a face-wall was built at the sides with free drainage, through rock packing and vitrified and cast-iron drains behind it, to keep this water from flowing over the tops of the bench-walls, and also to keep the lines of conduits dry.

The retaining walls were built in 25-ft. sections, the joints corresponding to those in the benches, being at the even stations, +08, +33, +58, and +83. **V**-shaped joints were made down the face, and the ends of the sections were made as shown by Fig. 19. The back part of the joint was mopped with hot pitch before the next section was built, so that there was practically no bond between any two adjoining sections.

The concrete in these walls was placed late in the season, and the expansion cracks, which were entirely confined to the **V**-shaped joints, were quite small even in the coldest weather of the following winter, nor were there any indications during the past summer of any stresses due to expansion. The coping and drain at the top of the wall were built together, but separate from the rest of the wall, the joint being made as shown in the sketch on Fig. 19. Thus far, there has seemed to be no seepage through either the vertical or horizontal joints.

The portal is built of granite, a half elevation being shown on Fig. 19, the stone being supplied by the Millstone Granite Company, Millstone Point, Conn. Fig. 3, Plate XXVII, shows the portal and the cut-and-cover section after the arches were completed but not covered.

The forms for the concrete in the approach were made of ordinary dressed lumber, and the surface was rubbed twice after the forms were removed, which was as soon as possible after the concrete had set. The surface was first very lightly rubbed with a piece of soft, light-colored, sandstone to remove any irregularities, being wetted slightly if necessary while being rubbed. After the concrete had become fairly hard and dry, it was rubbed a second time and a uniform texture and color obtained. The completion of this work was delayed until the second week in January, and considerable difficulty was encountered in obtaining a good finish of that part which was built after

cold weather set in, when it was necessary to protect it from frost. Unless extreme care was taken to prevent freezing after the rubbing, the entire surface was likely to scale off, although no cement or other material was added to it after the removal of the forms. A general view of the completed approach is shown by Fig. 4, Plate XXVII.

TABLE 6.

Title.	Day.			Night.		
	No.	Rate.	Amount.	No.	Rate.	Amount.
Walking bosses	2	$5.00	$10.00			
Timekeeper	2	3.00	6.00			
Watchmen				5	$2.00	$10.00
Waterboys	1	1.50	1.50			
Carpenter foremen	2	3.50	7.00	1	4.00	4.00
Carpenters	14	2.50	35.00	8	2.50	20.00
Pipe-fitters	1	3.00	3.00			
Pipe-fitter's helper	1	1.75	1.75			
Wheelwright	1	2.75	2.75			
Wheelwright's helper	1	1.75	1.75			
Blacksmith	1	3.00	3.00			
Blacksmith's helper	1	1.75	1.75			
Foremen riggers	1	3.00	3.00			
Riggers	6	1.75	10.50			
Foremen trackmen	1	3.00	3.00			
Trackmen	6	1.50	9.00			
Machinist	2	3.00	6.00			
Machinist's helper	1	1.75	1.75			
Electrician	2	3.00	6.00	1	2.50	2.50
Electrician's helper	1	1.75	1.75			
Lampman	1	1.50	1.50			
Pumpman	1	1.50	1.50			
Finishers	3	2.50	7.50			
Hoist engineers	12	3.00	36.00			
Dinky engineers	5	2.75	13.75	1	2.75	2.75
Brakemen	5	1.75	8.75	1	1.75	1.75
Switchmen	1	1.50	1.50			
Barnmen	1	2.00	2.00	1	2.50	2.50
Drivers	9	1.50	13.50			
Foremen ductmen				2	2.50	5.00
Ductmen				5	2.00	10.00
Foremen laborers	13	3.50	45.50	2	3.50	7.00
Laborers	120	1.75	210.00	20	1.75	35.00
Compressor engineer	1	3.50	3.50	1	3.50	3.50
Firemen	2	2.50	5.00	1	2.50	2.50
Oiler	1	1.75	1.75			
Coal passers	2	1.75	3.50	1	1.75	1.75
Totals	324		$469.75	50		$108.25
Total daily labor expense						$578.00

The water finding its way into the side ditches in the approach, which of course included all rain falling in this area, was intercepted just inside the portal and carried back to the mouth of the cut through 24-in. cast-iron pipes laid beneath the conduits in the central bench-wall, thus disposing by natural drainage of a not inconsiderable

quantity of water which would otherwise have flowed through the tunnels to the sump at the Weehawken Shaft, from which it would have had to be pumped to the surface.

About 100 ft. of the tunnel immediately east of the Hackensack Portal was built by the cut-and-cover method, and the arch section used in the tunnel was modified by widening the haunches, the thickness of the arch at the crown being gradually increased from 22 in. at the portal, Station 324, to 34 in. at Station 323, where the regular segmental timbering at the tunnel commenced. A general view of the approach during construction is shown by Fig. 1, Plate XXV.

Contractor's Organization.

Table 6 shows approximately the number of men employed daily on the tunnel lining, by both the contractor and the sub-contractors, their occupation, the average rate of wages and the total daily expense for labor when the work was in full swing.

Engineering Organization.

The whole of the work of the North River Division was designed and executed under the direction of Charles M. Jacobs, M. Am. Soc. C. E., Chief Engineer, and James Forgie, M. Am. Soc. C. E., Chief Assistant Engineer, the construction of Section "K," Bergen Hill Tunnels, being directly in charge of the writer as Resident Engineer.

PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD COMPANY,
SECTION "K"—BERGEN HILL TUNNELS.

Organization of Staff of Resident Engineer.

Organization Previous to the Holing Through of the Tunnels.

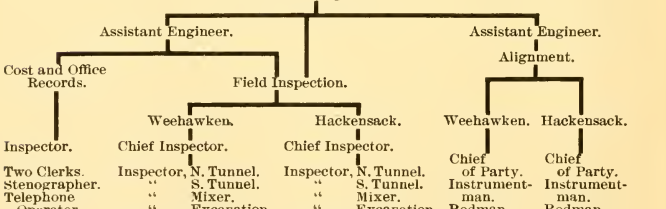


Fig. 20.

ORGANIZATION AFTER THE TUNNELS HAD BEEN HOLED THROUGH.

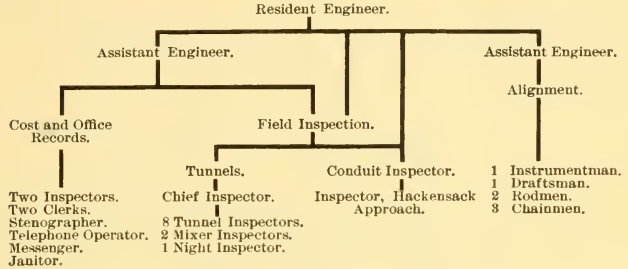


FIG. 21.

The general organization of the staff is shown by the two diagrams, Figs. 20 and 21. Fig. 20 shows the organization previous to the holing through of the tunnels, during which time a separate office was maintained at the western end for the use of the men stationed there; Fig. 21 shows the organization during the latter part of the time, after the tunnels were holed through. The Assistant Engineer in charge of the construction was J. R. Taft, Assoc. M. Am. Soc. C. E.; the Chief Inspector, J. S. Frazer, Jun. Am. Soc. C. E., had charge of about 75% of the work of the lining of the tunnels. The alignment has been from the beginning under the charge of R. L. Reynolds, Assistant Engineer.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1155

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

THE NORTH RIVER TUNNELS.*

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Introduction.

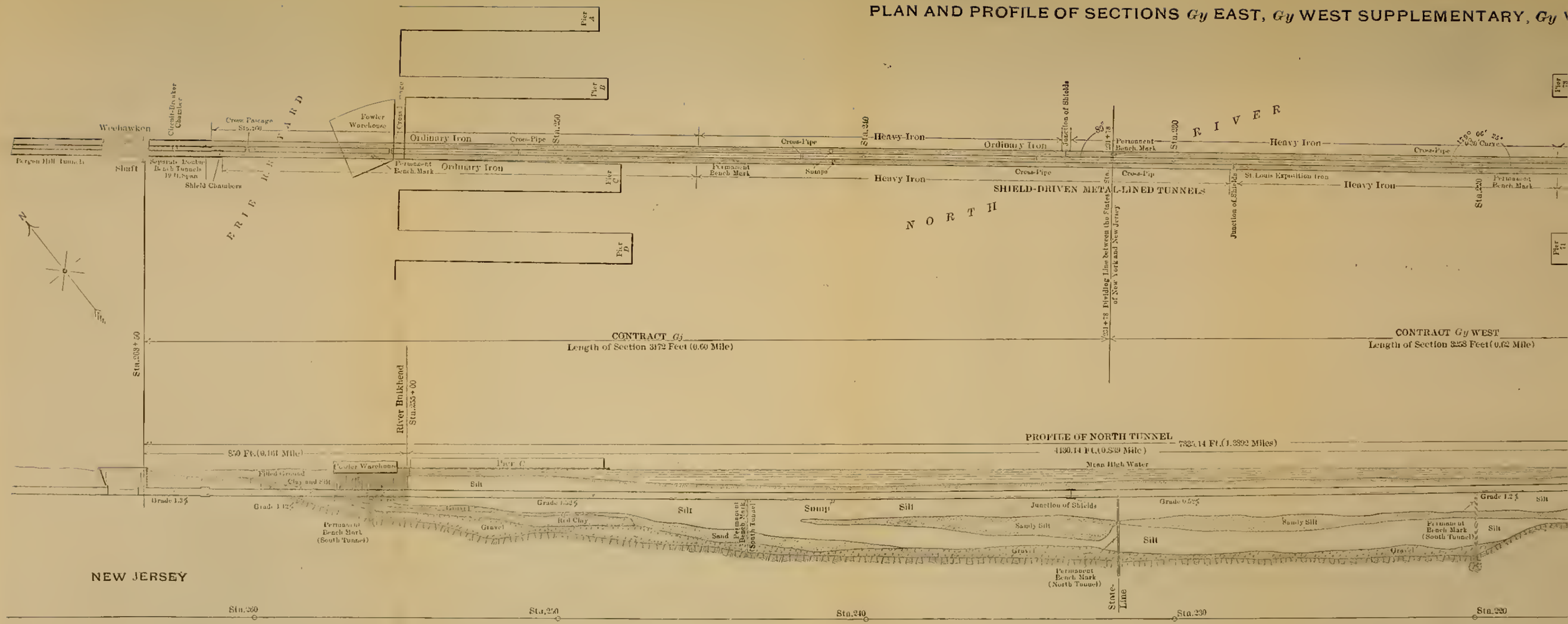
The section of the Pennsylvania Railroad Tunnel work described in this paper is that lying between Tenth Avenue, New York City, and the large shaft built by the Company at Weehawken, N. J., and thus comprises the crossing of the North or Hudson River, the barrier which has stood for such a long time between the railroads and their possession of terminal stations in New York City. The general plan and section, Plate XXVIII, shows the work included.

This paper is written from the point of view of those engaged by the Chief Engineer of the Railroad Company to look after the work of construction in the field. The history of the undertaking is not included, the various phases through which many of the designs and plans passed are not followed, nor are the considerations regarding foundations under the subaqueous portions of the tunnels and the various tests made in connection with this subject set out, as all these matters will be found in other papers on these tunnels.

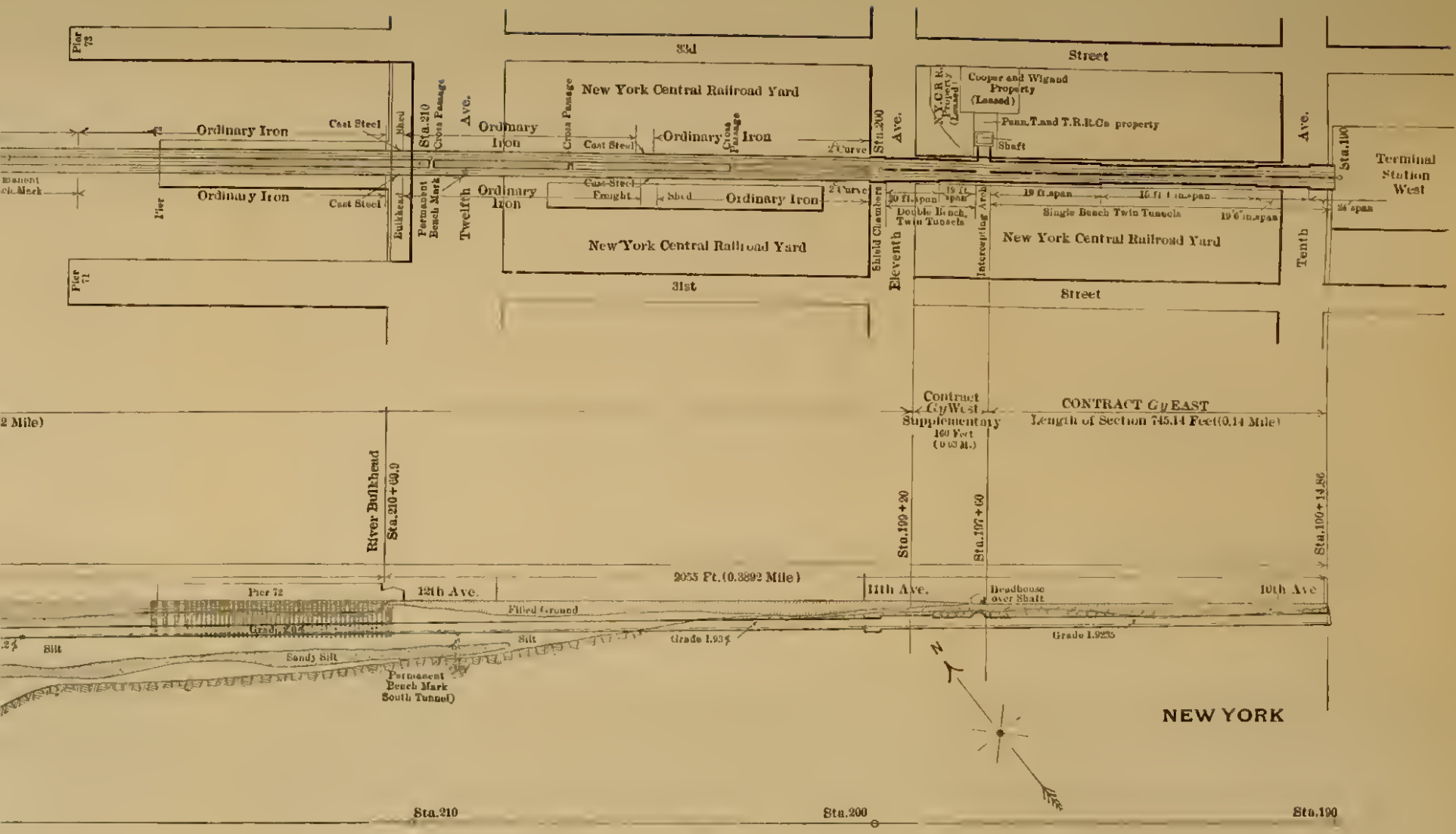
This paper only aims to describe, as briefly as possible, the actual designs which were finally adopted, the actual conditions met on the ground, and the methods of construction adopted by the contractors.

* Presented at the meeting of June 1st, 1910.

PLAN AND PROFILE OF SECTIONS *Gy* EAST, *Gy* WEST SUPPLEMENTARY, *Gy* W



RY, *Gy* WEST, AND *Gj*



For easy reference, and to keep the descriptions of work of a similar character together, the subject will be treated under the four main headings, viz.: Shafts, Plant, Land Tunnels, and River Tunnels.

Shafts.

It is not intended to give much length to the description of the Shafts or the Land Tunnels, as more interest will probably center in the River Tunnels.

The shafts did not form part of the regular tunnel contract, but were built under contract by the United Engineering and Contracting Company while the contract plans for the tunnel were being prepared. In this way, when the tunnel contracts were let, the contractor found the shafts ready, and he could get at his work at once.

Two shafts were provided, one on the New York side and one on the New Jersey side. Their exact situation is shown on Plate XXVIII. They were placed as near as possible to the point at which the disappearance of the rock from the tunnels made it necessary to start the shield-driven portion of the work.

The details of the shafts will now be described briefly.

The Manhattan Shaft.—The Manhattan Shaft is located about 100 ft. north of the tunnel center; there was nothing noticeable about its construction. General figures relating to both shafts are given in Table 1.

The Weehawken Shaft.—The Weehawken Shaft is shown in Fig. 1. This, as will be seen from Table 1, was a comparatively large piece of work. The shaft is over the tunnels, and includes both of them. In the original design the wall of the shaft was intended to follow in plan the property line shown in Fig. 2, and merely to extend down to the surface of the rock, which, as disclosed by the preliminary borings, was here about 15 ft. below the surface. However, as the excavation proceeded, it was found that this plan would not do, as the depth to the rock surface varied greatly, and was often much lower than expected; the rock itself, moreover, was very treacherous, the cause being that the line of junction between the triassic sandstone, which is here the country rock, and the intrusive trap of the Bergen Hill ridge, occurs about one-third of the length of the shaft from its western end, causing more or less disintegration of both kinds of rock. Therefore it

TABLE 1.—Particulars of Shafts on the North River Tunnels of the Pennsylvania Railroad Tunnels into New York City.

Location.	Depth, in feet.	Width, in feet.	Length, in feet.	Excavation (including drifts), in cubic yards.	Concrete, in cubic yards.	Date commenced.	Date finished.	Ground met:	Lined with:	Cost to Railroad Company.	Cost per cubic foot.
Manhattan: 11th Avenue and 32d Street.....	55	22	32	2 010	209	June 10th, 1903.	December 11th, 1903.	Top 13 ft. filled; red mica schist and granite.	Concrete reinforced with steel beams down to rock.	$12 943.75	$0.335
Weehawken: Baldwin Avenue.	76	At bottom 56, at top 100.	At bottom 115.75, at top 154.	55 315	9 810	June 11th, 1903.	September 1st, 1904.	Top 6 ft. filled, 30 ft. sand and hardpan, decomposed rock (trap and sandstone) below.	Concrete with steel tie-rods in rock.	166 162.93	0.337

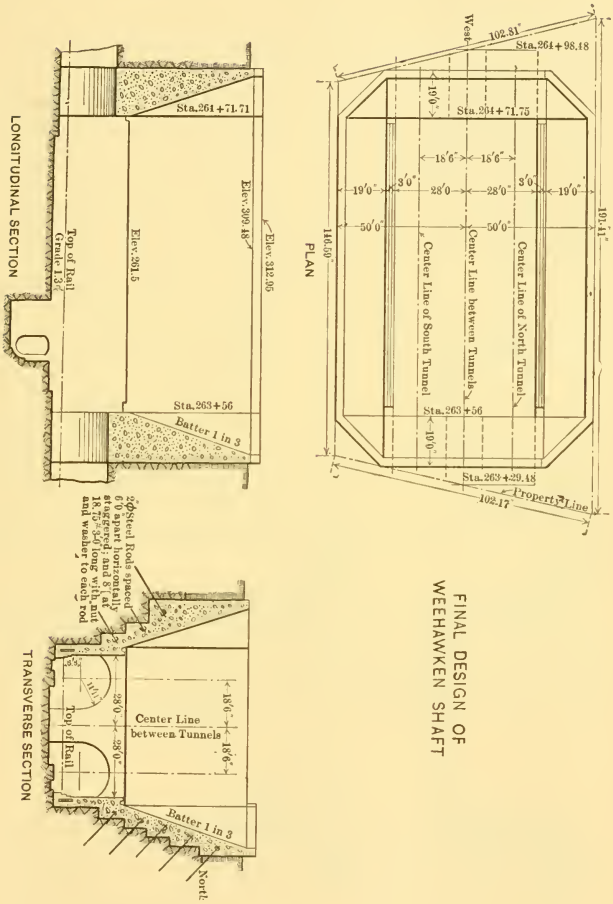

LONGITUDINAL SECTION
Sta.261+71.71
Elev.309.48
Elev.312.95
Elev.261.5
Top of Rail
Grade 1.3
Sta.263+56
Batter 1 in 3
TRANSVERSE SECTION
2" Steel Rods spaced 6'0" apart horizontally staggered; and 8" at 18.75" long with nut and washer to each rod
Top of Rail
Center Line between Tunnels
18'6"
28'0"
Batter 1 in 3
North
PLAN
West
102.81'
Sta.264+98.48
19'0"
Sta.264+71.75
18'6"
3'0"
28'0"
50'0"
146.50'
191.41'
Center Line of South Tunnel
Center Line between Tunnels
Center Line of North Tunnel
Sta.263+56
Sta.263+29.48
Property Line
102.17
FINAL DESIGN OF WEEHAWKEN SHAFT

FIG. 1.

was decided to line the shaft with concrete throughout its entire depth, the shape being changed to a rectangular plan, as shown in the drawings. At the same time that the shaft was excavated, a length of 40 ft. of tunnels at each end of it was taken out, also on account of the treacherous nature of the ground, thus avoiding risk of injury to the shaft when the tunnel contractors commenced work. There was much trouble with floods during the fall of 1903, and numerous heavy falls of ground occurred, in spite of extreme care and much heavy timbering. The greatest care was also taken in placing the concrete lining, and the framing to support the forms was carefully designed and of heavy construction; the forms were of first-class workmanship, and great care was taken to keep them true to line. A smooth surface was given to the concrete by placing a 3-in. layer of mortar at the front of the walls and tamping this dry facing mixture well down with the rest of the concrete. The east and west walls act as retaining walls, while those on the north and south are facing walls, and are tied to the rock with steel rods embedded and grouted into the rock and into the concrete. Ample drainage for water at the back of the wall was provided by upright, open-joint, vitrified drains at frequent intervals, with dry-laid stone drains leading to them from all wet spots in the ground. A general view of the finished work is shown in Fig. 1, Plate XXIX, and Table 1 gives the most important dates and figures relating to this shaft.

After the tunnel work was finished, both shafts were provided with stairs leading to the surface, a protective head-house was placed over the New York Shaft, and a reinforced concrete fence, 8 ft. high, was built around the Weehawken Shaft on the Company's property line, that is, following the outline of the shaft as originally designed.

Plant.

Working Sites.

Before beginning a description of the tunnel work, it may be well to set out in some detail the arrangements made on the surface for conducting the work underground.

All the work was carried on from two shafts, one at Eleventh Avenue and 32d Street, New York City—called the Manhattan Shaft

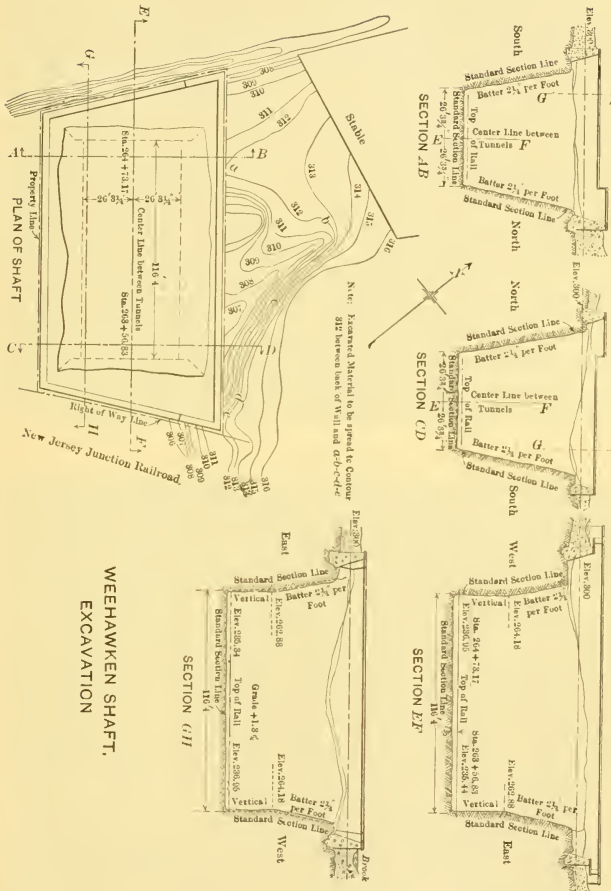


Fig. 2.

WEEHAWKEN SHAFT.
EXCAVATION

—and one at Baldwin Avenue, Weehawken, N. J.—called the Weehawken Shaft.

The characteristics of the two sites were radically different, and called for different methods of handling the transportation problem. The shaft site at Manhattan is shown on Plate XXX. It will be seen that there was not much room, in fact, the site was too cramped for comfort; the total area, including the space occupied by the old foundry, used for power-houses, offices, etc., was about 3 250 sq. yd. This made it necessary to have two stages, one on the ground level for handling materials into the yard, and an overhead gantry on which the excavated materials were handled off the premises. The yard at Weehawken was much larger; it is also shown on Plate XXX. Its area was about 15 400 sq. yd. in the yard proper, and there was an additional space of about 750 sq. yd. alongside the wharf at the "North Slip," on the river front, connected with the main portion of the yard by an overhead trestle.

All the cars at Manhattan were moved by hand, but at Weehawken two electric locomotives with overhead transmission were used.

Power-House Plant.

At the Manhattan Shaft the power-house plant was installed on the ground floor of the old foundry building which occupied the north side of the leased area. This was a brick building, quite old, and in rather a tumble-down condition when the Company took possession, and in consequence it required quite a good deal of repair and strengthening work. The first floor of the building was used by the contractor as offices, men's quarters, doctor's offices, and so on, and on the next one above, which was the top floor, were the offices occupied by the Railroad Company's field engineering staff.

On the Weehawken side, the plant was housed in a wooden-frame, single-story structure, covered with corrugated iron. It was rectangular in plan, measuring 80 by 130 ft.

At both sides of the river the engines were bedded on solid concrete on a rock foundation.

The installation of the plant on the Manhattan side occupied from May, 1904, to April, 1905, and on the Weehawken side from September, 1904, to April, 1905. Air pressure was on the tunnels at the New York side on June 25th, 1905, and on the Weehawken side on the 29th of the same month.

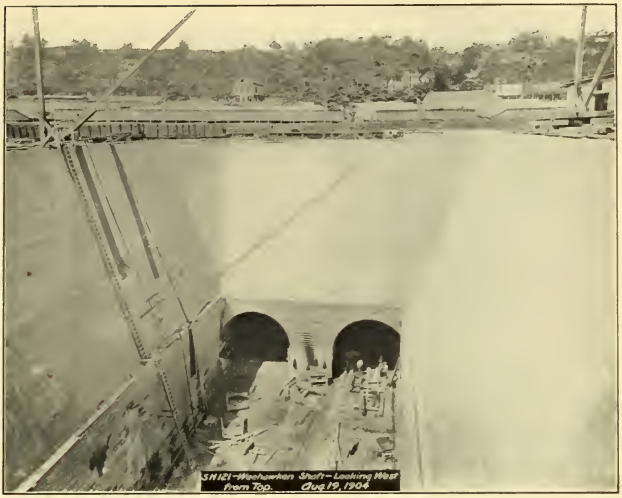

SH121-Weehawken Shaft-Looking West
from Top. Aug. 19, 1904

FIG. 1.

A 8 N.R.D. Section Gy West. North Tube Tunnel Manhattan
Face View of Shield during Construction Looking East.
March 29, 1905.

FIG. 2.

The plants contained in the two power-houses were almost identical, there being only slight differences in the details of arrangement due to local conditions. A list of the main items of the plant at one power-house is shown in Table 2.

TABLE 2.—Plant at One Power-House.

No. of items.	Description of item.	Cost.
Three	500-h.p. water-tube Sterling boilers	$15 186
Two	Feed pumps, George F. Blake Manufacturing Company	740
One	Henry R. Worthington surface condenser	6 539
Two	Electrically-driven circulating pumps on river front	5 961
Three	Low-pressure compressors, Ingersoll-Sergeant Drill Company	33 780
One	High-pressure compressor, Ingersoll-Sergeant Drill Company	6 665
Three	Hydraulic power pumps, George F. Blake Manufacturing Company	3 075
Two	General Electric Company's generators coupled to Ball and Wood engines	7 626
	Total cost of main items of plant	$79 572

Summary of Cost of One Plant.

Total cost of main items of plant	$79 572
Cost of four shields (including installation, demolition, large additions and renewals, piping, pumps, etc.)	108 560
Cost of piping, connections, drills, derricks, installation of offices and all miscellaneous plant	101 818
Cost of installation, including preparation of site	39 534
Total prime cost of one power-house plant	$324 484

The following is a short description of each item of plant in Table 2:

Boilers.—At each shaft there were three 500-h.p., water-tube boilers, Class F (made by Sterling and Company, Chicago, Ill.). They had independent steel stacks, 54 in. in diameter and 100 ft. above grate level; each had 5 000 sq. ft. of heating surface and 116 sq. ft. of grate area. The firing was by hand, and there were shaking grates and four doors to each furnace. Under normal conditions of work, two boilers at each plant were able to supply all the steam required. The average working pressure of the steam was 135 lb. per sq. in.

The steam piping system was on the loop or by-pass plan. The diameter of the pipes varied from 14 in. in the main header to 10 in. in the body of the loop. The diameter of the exhaust steam main increased from 8 in. at the remote machines to 20 in., and then to 30 in., at the steam separator, which in turn was connected with the condensers. A pipe with an automatic relief valve from the exhaust

to the atmosphere was used when the condensers were shut down. All piping was of the standard, flanged extra-heavy type, with bronze-seated gate-valves on the principal lines, and globe-valves on some of the auxiliary ones. There was an 8-in. water leg on the main header fitted with a Mason-Kelly trap, and other smaller water traps were set at suitable intervals.

Each boiler was fitted with safety valves, and there were automatic release valves on the high- and low-pressure cylinders of each compressor, as well as on each air receiver.

Buckwheat coal was used, and was delivered to the bins on the Manhattan side by teams and on the Weehawken side by railroad cars or in barges, whence it was taken to the power-house by 2-ft. gauge cars. An average of 20 tons of coal in each 24 hours was used by each plant.

The water was taken directly from the public service supply main. The daily quantity used was approximately 4 000 gal. for boiler purposes and 4 400 gal. for general plant use. Wooden overhead tanks having a capacity of 14 000 gal. at each plant served as a 12-hour emergency supply.

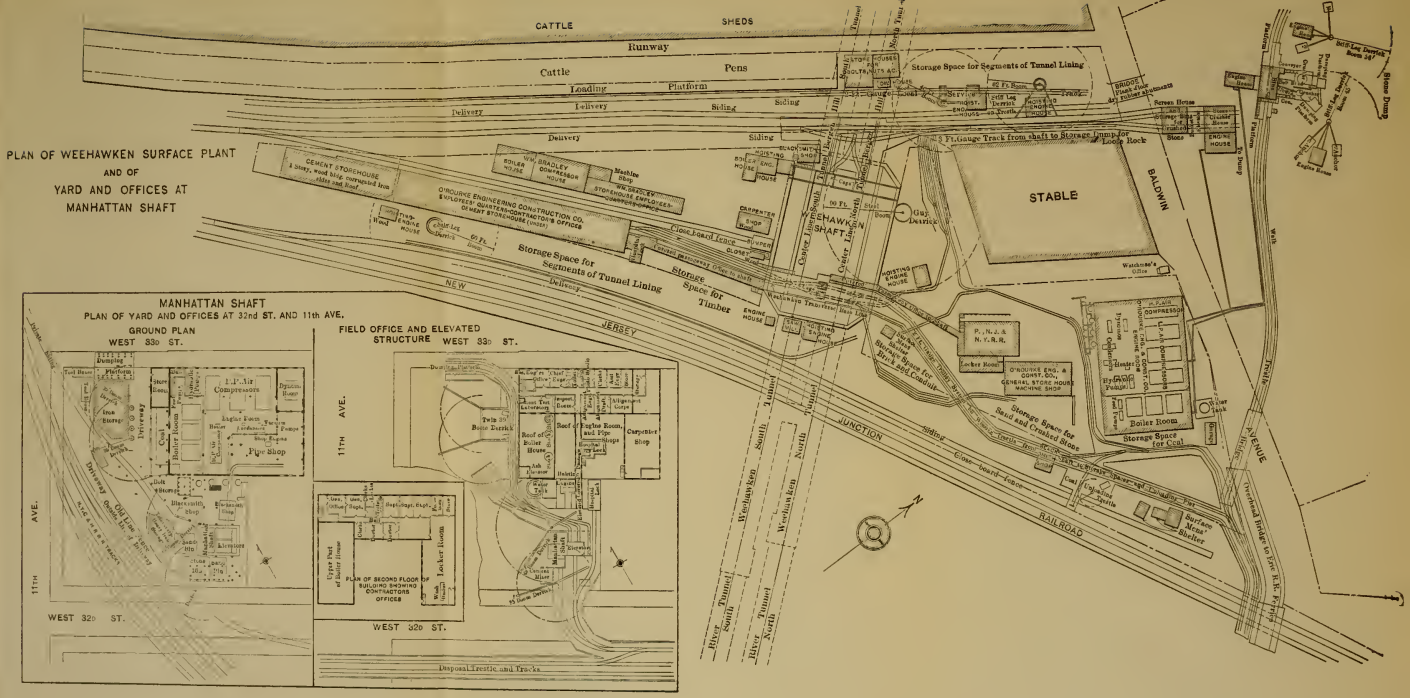
Feed Pumps.—There were two feed pumps at each plant. They had a capacity of 700 cu. ft. per min., free discharge. The plungers were double, of 6-in. diameter, and 10-in. stroke, the steam cylinders were of 10-in. diameter and 10-in. stroke. An injector of the "Metropolitan Double-Tube" type, with a capacity of 700 cu. ft. per min., was fitted to each boiler for use in emergencies.

The feed-water heater was a "No. 9 Cochrane," guaranteed to heat 45 000 lb. of water per hour, and had a total capacity of 85.7 cu. ft. It was heated by the exhaust steam from the non-condensing auxiliary plant.

Condenser Plant.—There were two surface condensers at each plant. Each had a cooling surface sufficient to condense 22 500 lb. of steam per hour, with water at a temperature of 70° Fahr. and barometer at 30 in., maintaining a vacuum of 26 in. in the condenser. Each was fitted with a Blake, horizontal, direct-acting, vacuum pump.

Circulating-Water Pumps.—Two circulating-water pumps, supplying salt water directly from the Hudson River, were placed on the wharf. They were 8-in. centrifugal pumps, each driven by a 36-h.p., General Electric Company's direct-current motor (220 volts and 610

PLAN OF WEEHAWKEN SURFACE PLANT
AND OF
YARD AND OFFICES AT
MANHATTAN SHAFT



rev. per min.), the current being supplied from the contractor's power-house generators. The pumps were run alternately 24 hours each at a time. Those on the Manhattan side were 1 300 ft. from the power-house, and delivered their water through a 16-in. pipe; those on the Weehawken side were 450 ft. away, and delivered through a 14-in. pipe. There was also a direct connection with the city mains, in case of an accident to the salt-water pumps.

Low-Pressure Compressors.—At each plant there were three low-pressure compressors. These were for the supply of compressed air to the working chambers of the subaqueous shield-driven tunnels. They were also used on occasions to supply compressed air to the cylinders of the high-pressure compressors, thus largely increasing the capacity of the latter when hard pressed by an unusual call on account of heavy drilling work in the rock tunnels. They were of a new design, of duplex Corliss type, having cross-compound steam cylinders, designed to operate condensing, but capable of working non-condensing; the air cylinders were simple duplex. The steam cylinder valves were of the Corliss release type, with vacuum dash-pots. The valves in the air cylinders were mechanically-operated piston valves, with end inlet and discharge. The engines used steam at 135 lb. pressure. The high- and low-pressure steam cylinders were 14 in. and 30 in. in diameter, respectively, with a stroke of 36 in. and a maximum speed of 135 rev. per min. The two air cylinders were 23½ in. in diameter, and had a combined capacity of 35.1 cu. ft. of free air per revolution, and, when running at 125 rev. per min., each machine had an actual capacity of 4 389 cu. ft. of free air per min., or 263 340 cu. ft. per hour. The air cylinders were covered by water-jackets through which salt water from the circulating pumps flowed. A gauge pressure of 50 lb. of air could be obtained.

Each compressor was fitted with an automatic speed and air-pressure regulator, designed to vary the cut-off according to the volume of air required, and was provided with an after-cooler fitted with tinned-brass tube and eight Tobin-bronze tube-plates having 809 sq. ft. of cooling surface; each one was capable of reducing the temperature of the air delivered by it to within 10° Fahr. of the temperature of the cooling water when its compressor was operated at its fullest capacity. From the after-cooler the air passed into a vertical receiver, 4 ft. 6 in. in diameter and 12 ft. high, there being

one such receiver for each compressor. The receivers were tested to a pressure of 100 lb. per sq. in. The after-coolers were provided with traps to collect precipitated moisture and oil. The coolers and receivers were fitted with safety valves set to blow off at 1 lb. above the working pressure. The air supply was taken from without, and above the power-house roof, but in very cold weather it could be taken from within doors.

High-Pressure Compressors.—There was one high-pressure compressor at each plant. Each consisted of two duplex air cylinders fitted to a cross-compound, Corliss-Bass, steam engine. The two steam cylinders were 14 and 26 in. in diameter, respectively, and the air cylinders were 14¼ in. in diameter and had a 36-in. stroke. The air cylinder was water-jacketed with salt water supplied from the circulating water pumps.

The capacity was about 1 100 cu. ft. of free air per min. when running at 85 rev. per min. and using intake air at normal pressure, but, when receiving air from the low-pressure compressors at a pressure of 30 lb. per sq. in., the capacity was 3 305 cu. ft. of free air per min.; receiving air at 50 lb. per sq. in., the capacity would have been 4 847 cu. ft. of free air per min. This latter arrangement, however, called for more air than the low-pressure compressors could deliver. With the low-pressure compressor running at 125 rev. per min. (its maximum speed), it could furnish enough air at 43.8 lb. per sq. in. to supply the high-pressure compressor running at 85 rev. per min. (its maximum speed); and, with the high-pressure compressor delivering compressed air at 150 lb., the combined capacity of the arrangement would have been 4 389 cu. ft. of free air per min.

The air passed through a receiver, 4 ft. 6 in. in diameter and 12 ft. high, tested under a water pressure of 225 lb. per sq. in., before being sent through the distributing pipes.

Hydraulic Power Pumps.—At each power-house there were three hydraulic power pumps to operate the tunneling shields. One pump was used for each tunnel, leaving the third as a stand-by. The duplex steam cylinders were 15 in. in diameter with a 10-in. stroke; the duplex water rams were 2⅛ in. in diameter with a 10-in. stroke. The pumps were designed to work up to 6 000 lb. per sq. in., but the usual working pressure was about 4 500 lb. The piping, which was extra heavy hydraulic, was connected by heavy cast-steel screw coup-

lings having a hexagonal cross-section in the middle to enable tightening to be done with a bolt wrench. The piping was designed to withstand a pressure of 5 500 lb. per sq. in.

Electric Generators.—At each plant there were two electric generators supplying direct current for both lighting and power, at 240 volts, through a two-wire system of mains. They were of Type M-P, Class 6, 100 kw., 400 amperes, 250 rev. per min., 240 volts no load and 250 volts full load. They were connected direct to 10 by 20 by 14-in., center-crank, tandem-compound, engines of 150 h.p. at 250 rev. per min. A switch-board, with all the necessary fuses, switches, and meters, was provided at each plant.

Lubrication.—In the lubricating system three distinct systems were used, each requiring its own special grade of oil.

The journals and bearings were lubricated with ordinary engine oil by a gravity system; the oil after use passed through a "White Star" filter, and was pumped into a tank about 15 ft. above the engine-room floor.

The low-pressure air cylinders were lubricated with "High Test" oil, having a flash point of 600° Fahr. The oil was forced from a receiving tank into an elevated tank by high-pressure air. When the tank was full the high-pressure air was turned off and the low-pressure air was turned on, in this way the air pressure in the oil tank equalled that in the air cylinder being lubricated, thus allowing a perfect gravity system to exist.

The steam cylinders and the high-pressure air cylinders were fed with oil from hand-fed automatic lubricators made by the Detroit Lubrication Company, Detroit, Mich.

"Steam Cylinder" oil was used for the steam cylinders and "High Test" oil (the same as used for the low-pressure air cylinders) for the high-pressure air cylinders. The air cylinder and steam cylinder lubricators were of the same kind, except that no condensers were necessary. The steam cylinder and engine oil was caught on drip pans, and, after being filtered, was used again as engine oil in the bearings. The oil from the air cylinders was not saved, nor was that from the steam cylinders caught at the separator.

Cost of Operating the Power-House Plants.—In order to give an idea of the general cost of running these plants, Tables 3 and 4 are given as typical of the force employed and the general supplies needed

for a 24-hour run of one plant. Table 3 gives a typical run during the period of driving the shields, and Table 4 is typical of the period of concrete construction. In the latter case the tunnels were under normal air pressure. Before the junction of the shields, both plants were running continuously; after the junction, but while the tunnels were still under compressed air, only one power-house plant was operated.

TABLE 3.—COST OF OPERATING ONE POWER-HOUSE FOR 24 HOURS DURING EXCAVATION AND METAL LINING.

No.	Labor.	Rate per day.	Amount.
6	Engineers	$3.00	$18.00
6	Firemen	2.50	15.00
2	Oilers	2.00	4.00
2	Laborers	2.00	4.00
4	Pumpmen	2.75	11.00
2	Electricians	3.50	7.00
1	Helper	3.00	3.00
Total per day			$62.00
Total for 30 days			$1 860.00
	SUPPLIES.		
Coal (14 tons per day)		$3.25	$45.50
Water		7.00	7.00
Oil (4 gal. per day)		0.50	2.00
Waste (4 lb. per day)		0.07	0.28
Other supplies		1.00	1.00
Total per day			$55.78
Total for 30 days			$1 673.00
Total cost of labor and supplies for 30 days			$3 533.00

Stone-Crusher Plant.—A short description of the stone-crusher plant will be given, as it played an important part in the economy of the concrete work. In order to provide crushed stone for the concrete, the contractor bought (from the contractor who built the Bergen Hill Tunnels) the pile of trap rock excavated from these tunnels, which had been dumped on the piece of waste ground to the north of Baldwin Avenue, Weehawken, N. J.

The general layout of the plant is shown on Plate XXX. It consisted of a No. 6 and a No. 8 Austin crusher, driven by an Amex, single-cylinder, horizontal, steam engine of 120 h.p., and was capable of crushing about 225 cu. yd. of stone per 10-hour day. The crushers and conveyors were driven from a countershaft, in turn driven from the engine by an 18-in. belt.

TABLE 4.—Cost of Operating the One Plant for 24 Hours During Concrete Lining.

No.	Labor.	Rate per day.	Amount.
2	Engineers	$3.00	$6.00
2	Firemen	2.50	5.00
2	Pumpmen	3.00	6.00
1	Foreman Electrician	6.00	6.00
1	Electrician	3.00	3.00
1	Laborer	2.00	2.00
Total per day			$28.00
Total for 30 days			$840.00
	Supplies.		
Coal (14 tons per day)		$3.15	$44.10
Oil (4 gal. per day)		0.50	2.00
Water		13.00	13.00
Other supplies		2.00	2.00
Total per day			$61.10
Total for 30 days			$1 833.00
Total cost of labor and supplies for 30 days			$2 673.00

The process of crushing was as follows: The stone from the pile was loaded by hand into scale-boxes which were lifted by two derricks into the chute above the No. 6 crusher. One derrick had a 34-ft. mast and a 56-ft. boom, and was worked by a Lidgerwood steam hoister; the other had a 23-ft. mast and a 45-ft. boom, and was worked by a "General Electric" hoist. All the stone passed first through the No. 6 crusher, after which it was lifted by a bucket conveyor to a screen, placed about 60 ft. higher than and above the stone bin. The screen was a steel chute pierced by 2½-in. circular holes, and was on a slope of about 45°; in order to prevent the screen from choking, it

was necessary to have two men continually scraping the stone over it with hoes. All the stone passing the screen was discharged into a bin below with a capacity of about 220 cu. yd. The stone not passing the screen passed down a diagonal chute to a No. 8 crusher, from which, after crushing, it was carried back by a second bucket conveyor to the bin, into which it was dumped without passing a screen. The No. 8 crusher was arranged so that it could, when necessary, receive stone direct from the stone pile. The cars in which the stone was removed could be run under the bin and filled by opening a sliding door in the bottom of the bin. A track was laid from the bin to connect with the contractor's surface railway in the Weehawken Shaft yard, and on this track the stone could be transported either to the Weehawken Shaft direct, for use on that side of the river, or to the wharf, where it could be dumped into scows for transportation to New York.

The cars used were 3-cu. yd. side-dump, with flap-doors, and were hauled by two steam Dinky locomotives.

The average force employed was:

1 foreman	@	$3.00	per day.	Supervising.
24 laborers	"	1.75	" "	Loading scale-boxes for derricks.
4 laborers	"	1.75	" "	Feeding crushers.
2 laborers	"	1.75	" "	Watching screens to prevent clogging.
1 engineer	"	4.00	" "	Driving steam engine.
2 engineers	"	3.50	" "	On the derricks.
1 night watchman.				Watching the plant at night.

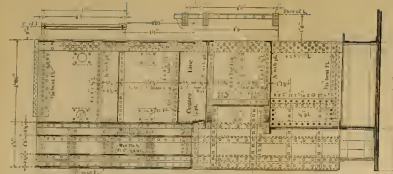
Owing to the constant break-down of machinery, chutes, etc., inseparable from stone-crushing work, there was always at work a repair gang consisting of either three carpenters or three machinists, according to the nature of the break-down.

The approximate cost of the plant was:

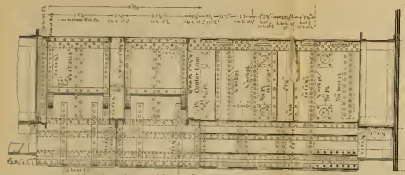
Machinery	$5 850
Lumber	3 305
Erection labor	3 999
Total	$13 154

PLATE XXXI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1155.
HEWETT AND BROWN ON
PENNSYLVANIA R. R. TUNNELS: NORTH RIVER TUNNELS.

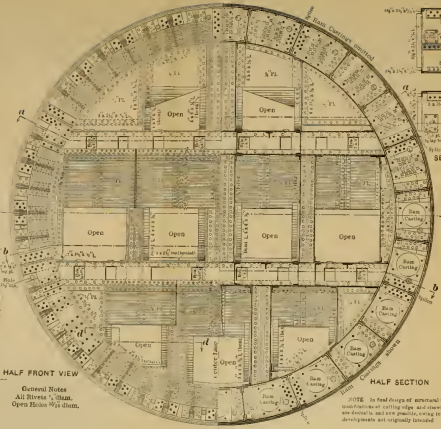
SHIELD FOR SUBAQUEOUS TUNNELING



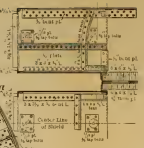
CROSS-SECTION ON LINE *a–a*, SHOWING UPPER RAM BOX.



CROSS-SECTION ON LINE *b–b*, SHOWING LOWER RAM BOX.



HALF FRONT VIEW

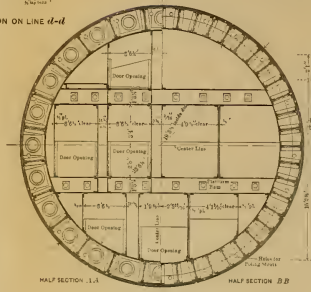


SECTION ON LINE *d–d*

HALF SECTION

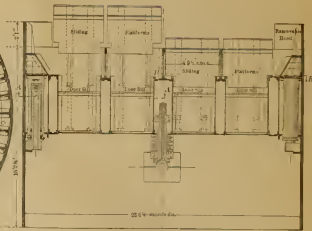
General Notes
All Rivets ⅞ diam.
Open Holes 9/16 diam.

NOTE. In final design of structural work, modifications of cutting edge and elsewhere are desired and are possible, owing to other developments not originally intended



HALF SECTION *A A*

HALF SECTION *B B*



HORIZONTAL SECTION THROUGH CENTER LINE

The cost of the crushed stone at Weehawken amounted to about $0.91 per cu. yd., and was made up as follows:

Cost of stone	$0.22
Labor in operation of plant	0.31
Plant supplies	0.11
*Plant depreciation	0.27
Total	$0.91

The crushed stone at the Manhattan Shaft cost about $1.04 per cu. yd., the difference of $0.13 from the Weehawken cost being made up of the cost of transfer across the river, $0.08, and transport from the dock to the shaft, $0.05.

Miscellaneous Plant.—The various pieces of plant used directly in the construction work, such as derricks, hauling engines, pumps, concrete mixers, and forms, will be found described or at least mentioned in connection with the methods used in construction.

The tunneling shields, however, will be described now, as much of the explanation of the shield-driven work will not be clear unless preceded by a good idea of their design.

Tunneling Shields.

During the period in which the original contract drawings were being made, namely, in the latter part of 1903 and the early part of 1904, considerable attention was given to working out detailed studies for a type of shield which would be suitable for dealing with the various kinds of ground through which the shield-driven tunnels had to pass. This was done in order that, when the contract was let, the engineer's ideas of the requirements of the shields should be thoroughly crystallized, and so that the contractor might take advantage of this long-thought-out design, instead of being under the necessity of placing a hurried order for a piece of plant on which so much of the safety as well as of the speed of his work depended. Eventually, the contractor took over these designs as they stood, with certain minor modifications, and the shields as built and worked gave entire satisfaction. The chief points held in view were ample strength, easy access to the working face combined with ease and quickness of closing the

* Assuming that the scrap value of derricks and engines is one-half the cost, crushers one-third the cost, and other items nothing.

diaphragm, and general simplicity. A clear idea of the main features of the design can be gathered from Fig. 3 and Plate XXXI.

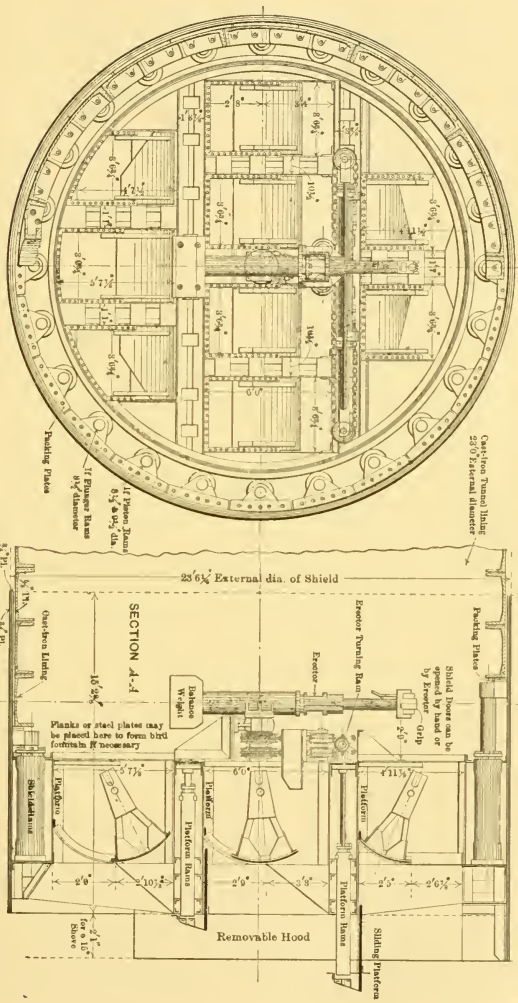
The interior diameter of the skin was 2 in. greater than the external diameter of the metal lining of the tunnel, which was 23 ft. The skin was made up of three thicknesses of steel plate, a $\frac{3}{4}$-in. plate outside and inside, with a $\frac{5}{8}$-in. plate between; thus the external diameter of the skin was 23 ft. $6\frac{1}{4}$ in. The length over all (exclusive of the hood, to be described later) was 15 ft. $11\frac{7}{16}$ in. The maximum overlap of the skin over the erected metal lining was 6 ft. $4\frac{1}{2}$ in., and the minimum overlap, 2 ft.

There were no inside or outside cover-plates, the joints of the various pieces of skin plates being butt-joints covered by the overlap of adjoining plates. All riveting was flush, both inside and outside. The whole circumference of each skin plate was made up of eight pieces, each of which extended the entire length of the shield, the only circumferential joint on the outside being at the junction of the removable cutting edge (or of the hood when the latter was in position) with the shield proper.

Forward of the back ends of the jacks, the shield was stiffened by an annular girder supporting the skin, and in the space between the stiffeners of which were set the 24 propelling rams used to shove the shield ahead by pressure exerted on the last erected ring of metal lining, as shown on Plate XXXI.

To assist in taking the thrust of these rams, gusset-plates were placed against the end of each ram cylinder, and were carried forward to form level brackets supporting the cast-steel cutting-edge segments. The stiffening gussets, between which were placed the rams, were also carried forward as level brackets, for the same purpose. The cast-steel segmental cutting edge was attached to the front of the last mentioned plates.

The interior structural framing consisted of two floors and three vertical partitions, giving nine openings or pockets for access to the face; these pockets were 2 ft. 7 in. wide, the height varying from 2 ft. 2 in. to 3 ft. 4 in., according to their location. The openings were provided with pivoted segmental doors, which were adopted because they could be shut without having to displace any ground which might be flowing into the tunnel, and while open their own weight tended to close them, being held from doing so by a simple catch.



PROPOSED SHIELD FOR SUBAQUEOUS TUNNELING
GENERAL ELEVATION
FIG. 3.

For passing through the varied assortment of ground before entering on the true sub-river silt, it was decided to adopt the forward detachable extension, or hood, which has so often proved its worth in ground needing timber for its support, as shown in Fig. 2, Plate XXIX. This hood extended 2 ft. 1 in. beyond the cutting edge, and from the top down to the level of the upper platform. Additional pieces were provided by which the hood might have been brought down as far as the lower platform, but they were not used. Special trapezoidal steel castings formed the junction between the hood and the cutting edge. The hood was in nine sections, built up of two $\frac{3}{4}$-in. and one $\frac{5}{8}$-in. skin plates, as in the main body of the skin, and was supported by bracket plates attached to the forward ends of the ram chambers. The hoods were bolted in place, and were removed and replaced by regular cutting-edge steel castings after the shields had passed the river lines.

The floors of the two platforms, of which there were eight, formed by the division of the platforms by the upright framing, could be extended forward 2 ft. 9 in. in front of the cutting edge, or 8 in. in front of the hood. This motion was given by hydraulic jacks. The sliding platform could hold a load of 7 900 lb. per sq. ft., which was equal to the maximum head of ground and water combined. The uses of these platforms will be described under the heading "Construction." The weight of the structural portion of each shield was about 135 tons.

The remainder of the shield was the hydraulic part, which provided its motive force and gave the power to the segment erector. The hydraulic fittings weighed about 58 tons per shield, so that the total weight of each shield was about 193 tons. The hydraulic apparatus was designed for a maximum pressure of 5 000 lb. per sq. in., a minimum pressure of 2 000 lb., and a test pressure of 6 000 lb. The actual average pressure used was about 3 500 lb. per sq. in.

There were 24 shoving rams, with a diameter of $8\frac{1}{2}$ in. and stroke of 38 in. The main ram was single-acting. The packings could be tightened up from the outside without removing the ram, a thing which is of the greatest convenience, and cannot be done with the differential plunger type. Some of the chief figures relating to the shield rams, with a water pressure of 5 000 lb. per sq. in., are:

Forward force of one ram	275 000 lb.
Forward force of 24 rams (all)	6 600 000 "
Forward force of 24 rams	3 300 tons of 2 000 lb.
Equivalent pressure per square inch of face	105 lb.
Eqivalent pressure per square foot of face	15 200 "
Pull-back force of one ram	26 400 "
Pull-back pressure on full area of ram	480 " per sq. in.

The rams developed a tendency to bend, under the severe test of shoving the shield all closed, or nearly so, through the river silt, and it is probable that it would have been better to make the pistons 10 in. in diameter instead of 8½ in.

Each sliding platform was actuated by two single-acting rams, 3½ in. in diameter and having a stroke of 2 ft. 9 in. The rams were attached to the rear face of the shield diaphragm inside the box floors, and the cylinders were movable, sliding freely on bearings in the floor. The front ends of the cylinders were fixed to the front ends of the sliding platforms. The cylinder thus supported the front end of the sliding platform, and was designed to carry its half of the load on the platform. Some of the leading figures in connection with the platform rams, at a working pressure of 5 000 lb. per sq. in., are:

Forward force of each pair of rams (in each platform)	96 000 lb.
Total area of nose of sliding platform	1 060 sq. in.
Maximum reaction per square inch on nose	90 lb.
Maximum reaction per square foot on nose	13 040 "

Each shield was fitted with a single erector mounted on the rear of the diaphragm. The erector consisted of a box-shaped frame mounted on a central shaft revolving on bearings attached to the shield. Inside of this frame there was a differential hydraulic plunger, 4 in. and 3 in. in diameter and of 48-in. stroke. To the plunger head were attached two channels sliding inside the box frame, and to the projecting ends of these the grip was attached. At the opposite end of the box frame a counterweight was attached which balanced about 700 lb. of the tunnel segment at 11 ft. radius.

The erector was revolved by two single-acting rams fixed horizontally to the back of the shield above the erector pivot through double chains and chain wheels keyed to the erector shaft.

The principal figures connected with the erector, assuming a water pressure of 5 000 lb. per sq. in., are:

Weight of heaviest tunnel segment	2 584 lb.
Weight of erector plunger and grip	616 "
Total weight to be handled by the erector ram	3 200 "
Total force in erector ram moving from center of shield	35 000 "
Total force in erector ram moving toward center of shield	27 500 "
Weight at 11-ft. radius which is balanced by counterweight	700 "
Maximum net weight at 11-ft. radius to be handled by turning rams	1 884 "
Total force of each rotating ram, at 5 000 lb. per sq. in.	80 000 "
Load at 11-ft. radius, equivalent to above	3 780 "

When the shield was designed, a grip was also designed by which the erector could handle segments without any special lugs being cast on them. A bolt was passed through two opposite bolt holes in the circumferential flanges of a plate. The grip jaws closed over this bolt and locked themselves. The projecting fixed ends of the grip were for taking the direct thrust on the grip caused by the erector ram when placing a segment.

It happened, however, that there was delay in delivering these grips, and, when the shield was ready to start, and the grip was not forthcoming, Mr. Patrick Fitzgerald, the Contractor's Superintendent, overcame this trouble by having another grip made.

In this design, also, a self-catching bolt is placed through the segment and the grip catches the bolt. In simplicity and effectiveness in working, this new design eventually proved a decided advance on the original one, and, as a result, all the shields were fitted with the new grip, and the original design was discarded.

The great drawback to the original grip was that the plate swung on the lifting bolt, and thus brought a great strain on the bolt when

erecting a plate in the crown, whereas in the new one, the plate was held rigidly at right angles to the erector arm. The original design was able to handle both *A* and *B* segments, and key segments, without alteration; in the new design, an auxiliary head had to be swung into position to handle the key, but this objection did not amount to a practical drawback.

The operating floor from which the shield was controlled, and at which the valves were situated, was placed above the rams which rotate the erector, and formed a protection for them. The control of the shield rams was divided into four groups: the seven lower rams constituted one group, the upper five, another, and the six remaining on each side, the other two. Each group was controlled by its own stop and release valve. Individual rams were controlled by stop-cocks.

The control of the sliding platform rams was divided into two groups, of which all the rams on the upper floor made one, and all those in the lower floor, the other; here, again, each group had its own stop and release valve, and individual platforms were controlled by stop-cocks arranged in blocks from which the pipes were carried to the rams.

The in-and-out movements of the erector ram were controlled by a two-spindle, balanced, stop and release valve, controlled by a hand-wheel. The erector rotating rams were controlled by a similar valve, with four spindles, also operated by a single hand-wheel. Both wheels were placed inside the top shield pockets, and within easy reach of the operating platform.

The hydraulic pressure was brought through the tunnel by a 2-in. hydraulic pipe. Connection with the shield was made by a flexible copper pipe, the 2-in. line being extended as the shield advanced.

Land Tunnels.

General.

The following is a brief account of the main features of the "Land Tunnel" work, by which is meant all the part of the structure built without using tunneling shields.

The Land Tunnels consist of about 977 ft. of double tunnel on the New York side and 230 ft. on the New Jersey side, or a total of 1 207 lin. ft. of double tunnel.

The general design of the cross-section consists of a semicircular arch, vertical side-walls and a flat invert. The tunnel is adapted for two lines of track, each being contained in its compartment or tunnel. The span of the arch is wider than is absolutely necessary to take the rolling stock, and the extra space is utilized by the provision of a side-walk or "bench" forming by its upper surface a gangway, out of the way of traffic, for persons walking in the tunnels, and embedded in its mass are a number of vitrified earthenware ducts, for high- and low-tension electric cables. The provision of this bench enables its vertical wall to be brought much nearer to the side of the rolling stock than is usually possible, thus minimizing the effects of a derailment or other accident. Refuge niches for trackmen, and ladders to the top of the bench are provided at frequent intervals. In cases where a narrow street limits the width of the structure, as on the New York side, the two tunnels are separated by a medial wall of masonry, thus involving excavation over the entire width of both tunnels, and in such case the tunnels are spoken of as "Twin Tunnels"; where the exigencies of width are not so severe, the two tunnels are entirely distinct, and are separated by a wall of rock. This type is found on the Weehawken side. The arches are of brick, the remainder of the tunnel lining being of concrete.

New York Land Tunnels.

The work on the Land Tunnels on the Manhattan side was carried on from the shaft at 11th Avenue and 32d Street.

The plans and designs for these tunnels are shown on Plate XXXII. In this short length of about 977 ft. there are no less than nine different kinds of cross-section. The reason for these changes is the fact that the two lines of track are here not straight and parallel to the center line between the tunnels, but are curved, although symmetrical about this center line. The various changes of section are to enable the tunnels to be built in straight lengths, thus avoiding the disadvantages attending the use of curved forms, and at the same time minimizing the quantity of excavation, an item which accounts for from 60 to 70% of the total cost of tunnels of this type. Of course, there are corresponding and obvious disadvantages in the adoption of many short lengths of different cross-sections, and these disadvantages were well brought out in the course of the work; on

PLATE XXXII.
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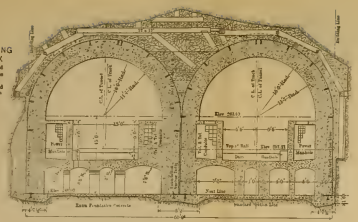
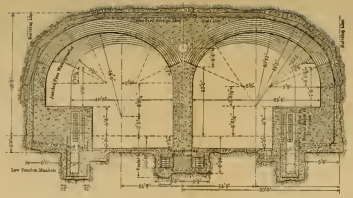
PENNSYLVANIA R. R. TUNNELS: NORTH RIVER TUNNELS.

METHOD OF BONDING BRICK ARCHWORK

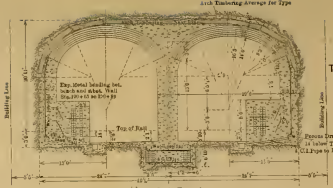
In order to obtain a bond between the different courses of brickwork, whenever a continuous joint was obtained through all courses, a double row of headers was put in. In order to have this uniform, the exact location of these joints was predetermined by calculation.



SHIELD CHAMBERS ARCH TIMBERING

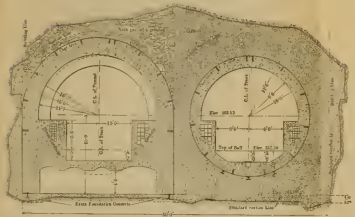


JUNCTION 19'6" AND 24'6" SPANS

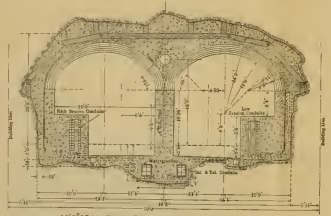


19'6" Span Twin Tunnels.

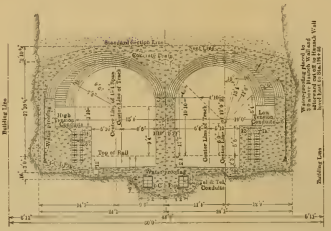
TYPICAL SECTIONS.
THIRTY-SECOND STREET TUNNELS
SHIELD CHAMBERS, ETC.

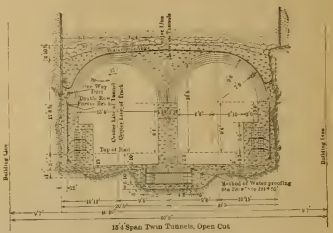


JUNCTION OF SHIELD CHAMBERS WITH RIVER TUNNELS



19'0" SPAN TWIN TUNNELS, ELLIPTICAL ARCHES





15'4" Span Twin Tunnels, Open Cut

the whole, however, they may be said to have justified their adoption. These New York Land Tunnels were divided into three contracts, viz.: From Station 190 + 15 (the Portal to the open work of the Terminal Station at the east side of Tenth Avenue, New York City) to Station 197 + 60, called "Section Gy-East." The next contract, called "Section Gy-West Supplementary," extended from Station 197 + 60 to Station 199 + 20, which is the east side of Eleventh Avenue. The third contract was called "Section Gy-West," and extended from Station 199 + 20 to Station 231 + 78 (the dividing line between the States of New York and New Jersey). Thus, for nearly all its length, this contract consists of shield-driven tunnel. The portion between Stations 199 + 20 and 199 + 91.5, however, was of the Land Tunnel type, and therefore will be included here. A fourth contract extended from Station 231 + 78 to the Weehawken Shaft at Station 263 + 50, and of this all but 230 ft. was of the shield-driven type, only the portion next to the Weehawken Shaft being of the Land Tunnel type.

The four contracts were let to one contractor (The O'Rourke Engineering Construction Company), and the work was carried on simultaneously in all four, so that the division into contracts had no bearing on the methods of work adopted, and these will now be described as a whole and with no further reference to the different sections.

Excavation.

Work was started on the New York side on April 18th, 1904, the Weehawken shaft being at that date still under construction. As will have been noted in the description of the shafts, the contractor found a shaft already prepared for his use, and cross-drifts at grade and at right angles to the future tunnels, and extending across their entire width. The first essential was to get access to the shield chambers, which were to lie about 330 ft. to the west of the shaft, so that the construction of these enlargements in which the shields for the subaqueous tunnels were to be built might be finished as soon as possible and thus allow the earliest possible start to be made with the shield-driven tunnels.

With this in view, two bottom headings, on the center line of each of the two tracks, were driven westward from the western cross-heading at the foot of the shaft. When about 138 ft. had been made in this

way, the two headings were brought together and a break-up was made to the crown level of the tunnel, as the depth of rock cover was doubtful. From this break-up a top heading was driven westward to Station 200 + 30. While widening the heading out at Station 200 + 20 the rock was penetrated on the south side. The exposed wet sand and gravel started to run, and, as a consequence, a change in design was made, the shield chambers (and consequently the start of the shield-driven tunnels) being moved eastward from their original location 133 ft. to their present location. A certain amount of time was necessarily spent in making these changes of design, which involved a rearrangement of the whole layout from the Terminal Station to the start of the River Tunnels. On July 5th, 1904, however, the new design was formally approved. No sooner had this been decided than a strike arose on the work, and this was not settled until August 1st, 1904, but from that time the work progressed without delay. No further reference will be made to the work in the shield chambers, as that will come under the heading of "River Tunnels," being of the segmental, cast-iron lined type.

A top heading was now driven over the original bottom heading west of the shaft, and at the same time the original cross-drifts from the shaft were amalgamated with and broken down by a heading driven at the crown level of the "Intercepting Arch" which here cuts across the ordinary run of tunnel at right angles and affords access to the tunnels from the shafts.

The excavation of the upper portion of the intercepting arch at its southern end gave some trouble, and caused some anxiety, as the rock cover was penetrated and the wet sand and gravel were exposed. This made it necessary to timber all this section heavily, and the tracks of the New York Central Railroad directly above were successfully supported. The general way in which this timbering was carried out will be described under the head of "Timbering."

Meanwhile, the excavation of the tunnels west of the intercepting arch was continued until the North and South Tunnels were taken out to their full outlines, leaving a core of rock between them. This core was gradually removed, and timbering supporting the rock above the middle wall was put in as excavation went on. The ground, which was entirely of micaceous schist, typical of this part of Manhattan, seamed with veins of granite, was rather heavy at the west end, or

PLATE XXXIII.
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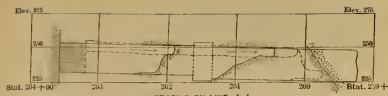
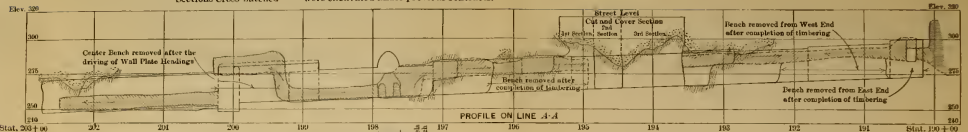
GENERAL METHOD OF EXCAVATION ADOPTED FOR LAND TUNNELS

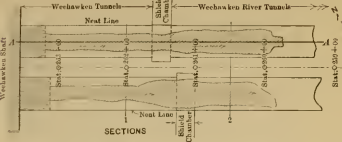
NOTE.-The Sub-divisions of each Cross-section are numbered in order as excavated
Sections Cross-hatched were excavated under previous contracts.



PROFILE ON LINE A-A



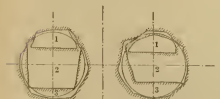
PROFILE ON LINE A-A



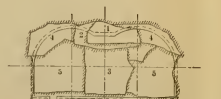
SECTIONS

PLAN SHOWING LOCATION OF ADVANCE HEADINGS

SECTION NO. 1
WEEHAWKEN TUNNELS


SECTION NO. 2
WEEHAWKEN RIVER TUNNELS

SECTION NO. 3
MANHATTAN RIVER TUNNELS


SECTION NO. 4
20' SPAN TWIN TUNNELS

SECTION NO. 5
INTERCEPTING ARCH

SECTION NO. 6
19' SPAN TWIN TUNNELS
DOUBLE BENCH

SECTION NO. 7
19' SPAN TWIN TUNNELS
SINGLE BENCH

SECTION NO. 8
19' SPAN TWIN TUNNELS ELLIPTICAL ARCHES
(SOFT ROOF SECTION)

SECTION NO. 9
19' SPAN TWIN TUNNELS ELLIPTICAL ARCHES
(ROCK SECTION)

SECTION NO. 10
15'4" SPAN TWIN TUNNELS
(CUT AND COVER SECTIONS)

SECTION NO. 11
15'4" SPAN TWIN TUNNELS
(TUNNEL SECTION)

SECTION NO. 12
19'6" SPAN TWIN TUNNELS

adjacent to the shield chambers, and required complete segmental timbering across the whole span. One heavy fall of rock in the core-wall between the North and South Tunnels took place on November 2d, but fortunately did not extend beyond the limits of the permanent work. On November 7th, 1904, the excavation east of the intercepting arch was begun by driving a bottom heading in the South Tunnel. This was continued to Station 197 + 14 and then was taken up to the crown level and worked as a top heading with the view of keeping track, by making exploratory borings upward from the roof at frequent intervals, of the rock surface, which was here irregular and not known with any degree of certainty. The work was not pressed with any vigor, because all efforts were then being bent toward excavating from the River Tunnels as much rock as possible. In Section Gy-East the conditions were exceptionally variable, as the rock was subject to sudden changes from a soft crumbling mica schist to broad bands of hard granite, and, in addition, the rock surface was very irregular, and, for a good length of this section, was below the crown of the tunnel, a condition which led to the adoption of the cut-and-cover method for part of the work.

The irregularity in conditions called for varying methods of procedure, but in general the methods were as shown on Plate XXXIII, and described as follows:

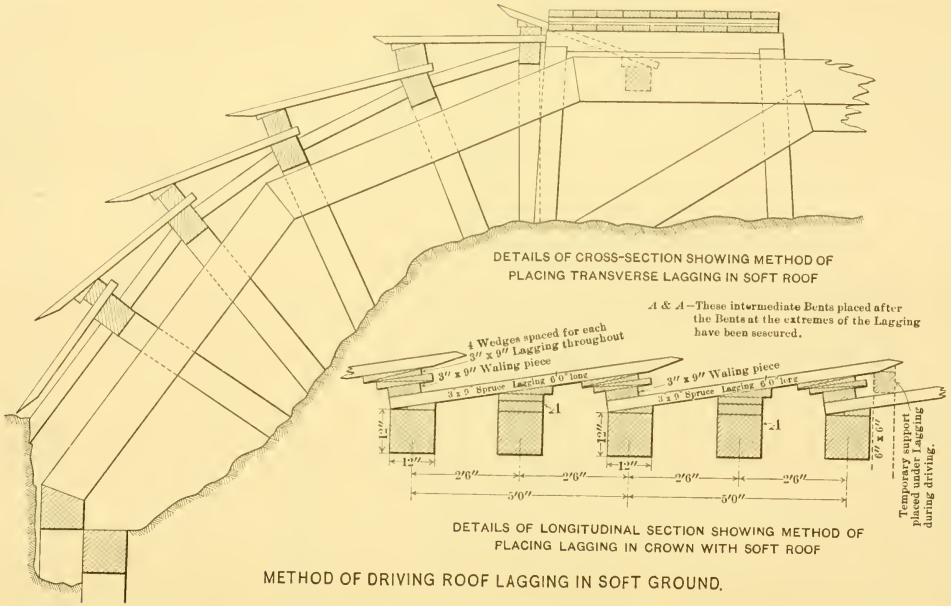
In Solid Rock.—Where there was plenty of good rock cover, a top middle heading was driven, which was afterward widened out to the full cross-section of the twin tunnel arches. If necessary, a few lengths of segmental timbering were put in before taking down the bench, which was generally kept some 40 or 50 ft. behind the breast of the heading. After the bench was down, the middle conduit trench was excavated and the trimming done.

In Soft Rock.—Where there was not enough rock cover, or where there was actual soft ground in the roof, wall-plate headings at the springing line level were driven ahead of the remainder of the work. The wall-plates were laid in these, the roof was taken out in short lengths, and segmental timbering spanning from wall-plate to wall-plate was put in. The roof being thus held, the bench excavation proceeded without trouble. Where the rock was penetrated and soft ground showed in the roof, poling boards were driven ahead over the crown-bars, as shown in Fig. 4.

Cut-and-Cover Work.—After some 225 ft. had been driven from the intercepting arch, it was found that the crown of the tunnel was continually in soft ground. To ascertain the extent of this condition the contractor decided to make soundings as far as Tenth Avenue, which was done by sinking trial pits and making wash-borings in the street. These soundings showed that there would be soft ground in the crown from Station 194 + 75 to Station 194 + 25 (at one point to a depth of 12 ft. below the crown), and on each side of this section the cover was insufficient from Station 193 + 58 to Station 195 + 30. This condition being known, it was decided to adopt cut-and-cover work for this length, the principal reasons being that repairs to sewers, streets, and drains would be no more, and probably less, expensive than with the tunnel method; the underpinning of a heavy brick brewery building adjoining the works on the north side would be facilitated, and the opening in the street, through which muck and materials could be handled, would relieve the congested shaft, through which the large volume of muck from the River Tunnels was then being conveyed. On the other hand, the cut-and-cover method was adversely affected by the presence of a heavy timber trestle built down the south side of the street and over which passed all the excavation from the Terminal Station, amounting to a very heavy traffic. As this trestle had to be supported, it complicated the situation considerably. Very little active progress was made between June, 1905, and April, 1906, as the contractor's energies during that time were much taken up with the progress of the shield-driven tunnels. In April, 1906, preparations were made to start a 50-ft. length of open cut, rangers being fixed and sheathing driven; and the sewer which ran down the middle of this street was diverted to the outside of the open-cut length.

April and May were occupied in driving the sheathing down to rock, supporting the trestle, underpinning the adjoining brewery, and excavating the soft material above the rock. On June 2d, 1906, rock was reached, and, by July 31st, the excavation was down to subgrade over nearly the whole 50 ft. in the first length. In the meantime another length was opened up, and eventually a third.

The surface of the rock now seemed to be rising, and the heavy buildings had been passed, so that tunneling was reverted to for the rest of the work, though many difficulties were caused by soft rock in the roof from time to time.



METHOD OF DRIVING ROOF LAGGING IN SOFT GROUND.

FIG. 4.

When the excavation for the open-cut work of the Terminal Station had advanced to the line of Tenth Avenue, the contractor started a heading from this point and drove westward under Tenth Avenue until the headings driven eastward from the cut-and-cover portion, were met.

This was done to expedite the work under Tenth Avenue, where the ground was not very good, where there were several important gas and water mains in the street, and where, moreover, the tunnels were of exceptionally large span (24 ft. 6 in.), making a total width of some 60 ft. for the excavation. The excavation for the New York Tunnels was practically finished in January, 1908.

Drilling and Blasting.—The foregoing short description will serve to show in a general way the scheme adopted in making the excavation. A few details on drilling and blasting methods may not be out of place.

Percussive drills run by air pressure were used. They were Ingersoll-Sergeant, Nos. 3½, A-86, C-24, and F-24. The air came from the high-pressure compressor previously described. This compressor, without assistance, could supply air for nine drills, but, when fed by compressed air from the lower pressure, its capacity was increased three or four times.

The air was compressed to 100 lb. per sq. in. in the power-house, and was delivered at about 80 lb. per sq. in. at the drills. A 3-in. air line was used. The drill steel was 1½- to 1⅝-in. octagonal. The holes were about 3¼ in. in diameter at starting and 2⅝ in. at the full depth of 10 ft. The powder used on the New York side was 40% Forcite, the near presence of heavy buildings and lack of much rock cover necessitating light charges and many holes spaced close together.

To compensate the contractor for the inevitable excavation done outside the neat lines of the masonry lining, the excavation was paid for to the "Standard Section Line" which was 12 in. outside the neat lines on top and sides and 6 in. outside at the bottom of the cross-section. The actual amount of excavation done was about 11% greater than that paid for. The distance excavated beyond the neat line, because of the very heavy timbering necessary, was about 2.1 ft. instead of the 1 ft. allowed, and at the bottom about 0.85 ft. instead of the 0.50 ft. paid for.

For a period of 5 months detailed records were kept of the drilling and blasting. About 12 900 cu. yd. of excavation are included. A

sketch and table showing the method of driving the heading, the number and location of the holes drilled, and the amount of powder used, is given in Fig. 5. From this and similar figures the information in Table 5 is derived.

TABLE 5.

Portion of excavation.	Feet of Hole Drilled per Cubic Yard of Excavation.			Pounds of Powder Used per Cubic Yard of Excavation.		
	15-ft. 4-in. span—twin tunnel.	19-ft. 6-in. span—twin tunnel.	24-ft. 6-in. span—twin tunnel.	15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.
Wall-plate heading*.....	13.0	10.97	10.97	3.77	2.85	2.85
Total heading*.....	7.87	8.17	7.81	2.31	2.02	1.78
Bench and raker bench*..	5.97	6.15	7.56	0.94	0.93	1.13
Trench*.....	9.82	15.96	18.10	1.84	2.49	2.73
Average for section*.....	6.69	7.43	8.95	1.28	1.30	1.45
Actual amount†.....	6.82	7.27	8.95	1.22	1.24	1.27

*Figures taken from typical cross-sections.

†This gives the actual amount of drilling done and powder used per cubic yard for the whole period of 5 months of observation, but as this length included 280 ft. of heading and only 220 ft. of bench, the average figures (for powder especially) are too low.

Table 6 gives the rate and cost of drilling, and the cost of powder. It will be seen that the average rate of drilling was 2.71 ft. per hour per drill or 27.1 ft. per drill per shift.

Table 7 shows the result of observation as to the time taken in various subdivisions of the drilling operations. These observations were not carried on for a long enough period to give correct results, but the percentages of time spent on each division of the operation are believed to be about right. The headings of this table are self-explanatory. The necessary delays include all time spent in changing bits, making air-line connections, etc. The unnecessary delays are stoppages caused by lack of supplies or insufficient air pressure.

By Table 6 it will be noticed that the cost of labor for drilling and sharpening steels was about $0.29 per lin. ft. of hole drilled. The total cost, including repairs, supply of air, etc., came to about $0.38, as will be seen from Table 8.

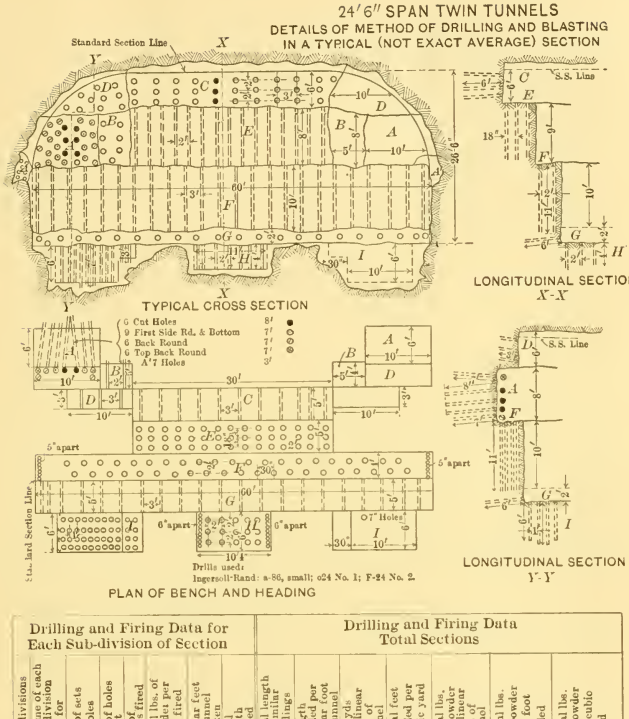
Timbering.—On the New York side nearly the whole length of the excavation needed timbering, to a greater or less extent, and for the most part required timbering of quite a heavy type.

TABLE 6.—Rock Tunnel Excavation under 32d Street, East of Cut-and-Cover Section. Drilling and Blasting.—Detailed Cost of Labor in Drilling, also Quantity and Cost of Powder Used.

Type.	Date. 1907	Drilling and Blasting. Total feet drilled. Heading.	Bench.	Total.	No. of drill shifts. (10-hour.) Heading.	Bench.	Total.	Feet drilled per man per hour. Heading.	Bench.	Total.	Quantity of excavation, in cubic yards. Actual.*	Paid for.†	Cost of labor only. Drilling and sharpening. Total.	Per linear feet.	Per cubic yard. Actual.	Paid for.	Powder Used. Total quantity.	Cost per cubic yard at 11 cents per pound. Actual.	Paid for.
													$	$	$		Pounds.	$	$
Ke.	May	2 971	5 578	8 549	98	204	302	3.031	2.734	2.831	1 736	1 664	2 331	0.27	1.34	1.40	1 595	0.16	0.10
	June	2 093	6 194	8 287	85	223	308	2.462	2.777	2.691	809	698	2 440	0.29	3.01	3.49	1 960	0.27	0.31
	July	.....	7 627	7 627	.....	268	268	.....	2.845	2.845	1 022	960	2 081	0.26	1.98	2.11	966	0.10	0.11
	Aug.	.....	2 552	2 552	.....	95	95	.....	2.688	2.688	743	716	640	0.25	0.86	0.89	430	0.06	0.07
	Sept.	.....	2 133	2 133	.....	79	79	.....	2.700	2.700	238	238	533	0.25	2.24	2.24	280	0.13	0.13
	Total	5 064	24 084	29 148	183	869	1 052	2.767	2.77	2.77	4 548	4 276	7 975	0.27	1.75	1.87	5 231	0.13	0.13
Ki.	May	6 976	.....	6 976	216	.....	216	3.229	.....	3.229	614	527	1 604	0.23	2.61	3.04	1 230	0.22	0.26
	June	4 089	.....	4 089	135	.....	135	3.029	.....	3.029	357	259	1 234	0.30	3.45	4.76	1 036	0.32	0.44
	July	.....	3 733	3 733	.....	140	140	.....	2.666	2.666	530	404	1 084	0.29	2.04	2.68	550	0.11	0.15
	Aug.	.....	6 715	6 715	.....	249	249	.....	2.769	2.769	925	890	1 901	0.28	2.05	2.13	905	0.10	0.11
	Estim.	.....	14 742	14 742	.....	546	546	.....	2.700	2.700	3 254	2 908	4 570	0.31	1.40	1.57	2 470	0.08	0.09
	Total	11 065	25 190	36 255	351	935	1 286	3.152	2.694	2.819	5 680	4 988	10 393	0.29	1.83	2.08	6 191	0.12	0.14
Ko.	May	.....	1 617	1 617	.....	55	55	.....	2.921	2.921	250	188	471	0.29	1.88	2.50	376	0.17	0.22
	June	.....	2 948	2 948	.....	107	107	.....	2.755	2.755	496	347	883	0.29	1.78	2.54	357	0.08	0.11
	July	.....	3 734	3 734	.....	131	131	.....	2.850	2.850	626	606	1 003	0.27	1.60	1.65	609	0.11	0.11
	Aug.	.....	8 260	8 260	.....	290	290	.....	2.848	2.848	718	709	2 161	0.26	3.00	3.04	918	0.14	0.14
	Estim.	.....	4 787	4 787	.....	285	285	.....	1.680	1.680	605	535	2 397	0.50	3.96	4.48	762	0.14	0.16
	Total	.....	21 346	21 346	.....	868	868	.....	2.460	2.460	2 695	2 385	6 915	0.32	2.57	2.90	3 022	0.12	0.14
Grand Total		16 129	70 620	86 749	534	2 672	3 206	3.020	2.710	2.710	12 923	11 649	25 283	0.29	1.96	2.17	14 444	0.12	0.14

The work done during the 5 months when these analyzed cost figures were kept includes 280 ft. of bench and 220 ft. of heading. This excess of bench over heading causes the general average amounts per cubic yard to be too low.

* Actual amount of excavation. † Amount of excavation paid for.



Sub-divisions	Volume of each sub-division paid for	No. of sets of holes	No. of holes in set	No. of fired holes	Total lbs. of powder per hole fired	Linear feet of tunnel broken	Total length drilled	Total length of annular headings	Length drilled per linear foot of tunnel	Cu. yds per linear foot of tunnel	Total feet drilled per cubic yard	Total lbs. of powder per linear foot of tunnel	Total lbs. of powder per foot drilled	Total lbs. of powder per cubic yard
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*
	17.775	• 1	6	3	4.50				$\frac{\Sigma c+d}{g}$	$\frac{b+j}{g}$	$\frac{j}{k}$	$\frac{c+d+f}{g}$	$\frac{m}{j}$	$\frac{m}{k}$
		○ 1	9	1	1.50									
		⊙ 1	6	1	1.00									
		⊚ 1	6	1	0.75	6.0	195	2	65.00	5.925	10.97	17.00	0.261	2.848
A	1.00	2	3-4	1	0.25	5.0	21	2	8.40	0.400	21.00	0.70	0.166	1.750
B	5.925	• 2	3-4	1	1.00	4.0	35	2	17.50	2.962	5.90	8.50	0.209	1.181
C		○ 1	3	2	1.125									
	33.33	4	7	1	1.125	5.0	186	1	37.20	6.666	5.58	6.975	0.187	1.046
D	6.665	2	5-6	1	0.75	3.0	33	2	22.00	4.444	4.95	5.500	0.250	1.237
		Total for Heading							150.10	20.397	7.81	33.675	0.227	1.778
E	50.00	9.0	5	1	1.50	5.0	405	1	81.00	10.000	8.10	13.500	0.167	1.350
F	88.88	10.5	1	2	1.50									
		+ 5.0	4	1	1.50	4.0	632	1	170.50	22.222	7.67	24.230	0.136	1.046
G	22.22	5.5	4	2	1.00	5.0	132	1	26.40	4.444	5.94	4.100	0.166	0.990
		Total for Bench							277.90	36.666	7.56	41.150	0.150	1.133
H	9.77	5	3	1	0.50									
		4	6	1	0.50	6.0	156	1	26.00	1.628	15.96	3.250	0.125	1.995
I	26.66	8	5	1	1.00	6.0	252	2	84.00	4.444	18.90	13.333	0.158	3.000
		Total of Trench							110.00	6.072	18.10	16.583	0.151	2.731
		Total for Whole Section							548.00	63.135	8.95	91.408	0.172	1.446
		* line holes						Powder taken at 0.5 lb. per stick						

Drilling and Firing Data for Each Sub-division of Section

Drilling and Firing Data Total Sections

FIG. 5.

TABLE 7.—Analysis of Drilling Time on Section Gy-East.

Position in Section.	Nature of Rock.	No. of Drill Shifts observed for average.	Average Time Taken:									Feet Drilled.	
			Setting up.	Drilling.	Necessary delays.	Unnecessary delays.	Taking down machine.	Loading and firing.	Total drilling.	Muckmg.	Total.	Per shift.	Per working hour.
			h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	.....	.....
Heading	Quartz	8	0 : 38	4 : 52	1 : 40	.....	0 : 05	0 : 04	7 : 19	2 : 41	10 : 00	22.0	2.86
Heading	Hard mica schist	1	0 : 15	8 : 00	1 : 45	.....	.....	.....	10 : 00	.....	10 : 00	42.0	4.20
Bench	Quartz	23	1 : 23	5 : 57	2 : 23	0 : 05	0 : 05	0 : 07	10 : 00	.....	10 : 00	25.9	2.59
Bench	Medium mica schist	16	1 : 10	6 : 08	1 : 50	0 : 12	0 : 07	0 : 07	9 : 34	0 : 26	10 : 00	22.22	2.32
Center trench	" " "	10	0 : 58	5 : 53	1 : 33	0 : 06	0 : 12	0 : 30	9 : 12	0 : 48	10 : 00	22.0	2.39
Center trench	Soft " "	9	1 : 10	6 : 40	1 : 17	0 : 10	0 : 20	0 : 23	10 : 00	.....	10 : 00	26.44	2.64
General average		67	1 : 08	5 : 58	1 : 53	0 : 07	0 : 09	0 : 12	9 : 27	0 : 33	10 : 00	24.1	2.54
Percentage		.....	11.3%	59.7%	18.9%	1.1%	1.5%	2%	94.5%	5.5%	100%	.....	.....

TABLE 8.—Analyzed Cost of Drilling.

Item of Cost.	Cost per Foot of Hole Drilled.				Cost per Drill Shift.			
	15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.	Average.	15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.	Average.
Drilling labor	$0.25	$0.28	$0.31	$0.28	$6.95	$7.75	$7.60	$7.45
Sharpening	0.02	0.02	0.01	0.016	0.53	0.42	0.34	0.43
Drill steel (5 in. per drill shift)	0.007	0.007	0.006	0.007	0.19	0.20	0.15	0.19
Drill repairs	0.02	0.02	0.02	0.02	0.61	0.59	0.42	0.54
High-pressure air	*0.05	0.04	0.07	0.07	1.39	1.86	1.67	1.82
Totals	$0.35	$0.38	$0.41	$0.385	$9.67	$10.82	$10.18	$10.43

* This is an estimated figure, ascertained by taking a proportion of the whole charge for plant running.

General Methods.—Whenever any considerable support was needed for the ground, segmental timbering was used. In most cases, this was supported by wall-plates at the springing line, and was set with an allowance for settlement, so that it would be clear of the work when the masonry lining was put in. As the twin-tunnel section involved the excavation of the North and South Tunnels at the same time, the cross-section of the upper part of the excavation consisted of two quadrants rising from the springing line and connected at the top by a horizontal piece from 19 to 28 ft. in length. This made a rather flat arch to support by timbering.

The timber for the segmental work was 12 by 12-in. yellow pine. In light ground the bents were spaced at 5-ft. centers, in heavy ground 2-ft. 6-in. centers.

When the soft ground in the roof was struck, posts had to be used in the heading to support the caps. When the bench was removed, the posts were replaced by others down to the bottom of the excavation. These long posts were a great hindrance to all the work, and each replacement of short posts by long ones meant a settlement of the caps; consequently, it was decided to use in the section east of the cut-and-cover, where all the ground was heavy, a temporary inner bent of segmental timber, within and reinforcing the permanent bent, and resting on separate wall-plates. This is shown by Fig. 6. These temporary bents were inside the work, and were removed as the arch was built. However, the caps settled considerably in some cases, so that it was not possible to do away with posting entirely.

In heavy ground the caps were set about 1 ft. above the neat line of the crown of the brick arch, in some cases they were set only 6 in. above, but the settlement was often more than this, causing great trouble in cutting out the encroaching timber when the arch had to be built.

In the tunnels east of the cut-and-cover portion, wall-plate headings were driven (shown by areas marked *A* on Fig. 5), and, when a length of wall-plate had been set, the full-width heading was advanced a foot

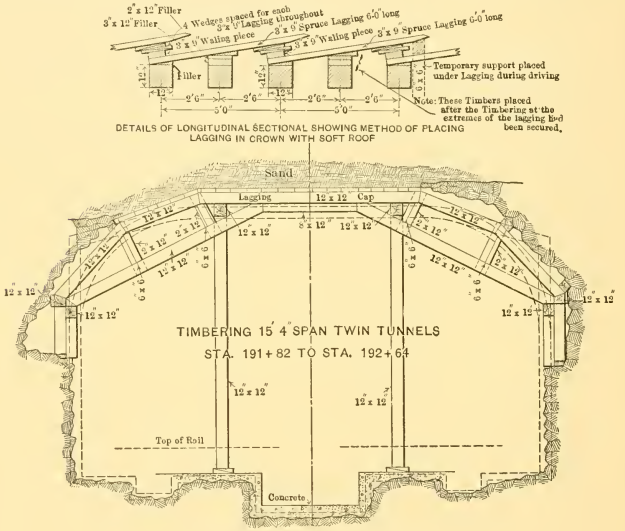


FIG. 6.

or two at a time, the timber segmental bents being set up as soon as possible; lagging was then driven over the cap into the soft ground. Fig. 6 shows the double set of segmental bents adopted in the 15-ft. 4-in. twin tunnels east of the cut-and-cover section.

When the soft ground came down so low as to interfere with the excavation of the wall-plate headings, a small heading was driven into the soft ground on the line of the ends of the caps, and lagging was driven down from this to the wall-plate heading, as illustrated in Fig. 4.

In the 19-ft. 6-in. tunnels the wall-plate for the inner bent was supported by a side-bench, termed the "Raker" bench. This was left in position until the rest of the bench and the middle subgrade conduit trench had been excavated; it was then possible to support the caps by two rows of posts from subgrade level, take out the inner bents, and excavate the raker bench.

The 24-ft. 6-in. twin tunnels, which are at the extreme eastern end of this section, adjoining the open-cut work of the Terminal Station, and under Tenth Avenue, were driven from the Terminal Station-West, and the timbering had to be made very secure on account of the pipes and sewers in the street above. Detailed records were kept of the amount of timber used and the cost of labor and material expended in timbering. These records cover the same portion of tunnel as that for which the detailed records of drilling costs, previously referred to, were kept. These records are shown in Tables 9 and 10. It will be noted that the timber used in blocking, that is, filling up voids outside the main timbering, amounted to more than two-thirds of the total timber, and that the cost of labor in erecting the timbering exceeds the prime cost of the timber by about one-third. The following distinction is made between permanent and temporary timbering: The permanent timbering is that which is concreted in when the masonry is built; the temporary consists of the lower bents and posts, which have to be removed when the masonry is built.

Force Employed in Excavation.—A typical day's working force for drilling, blasting, mucking, and timbering is shown in Table 11.

Where there was any large quantity of soft ground in the roof, the timber gang was much larger than shown in Table 11, and was helped by the mucking gang. The drillers did most of the mucking out of the heading before setting up the drills.

Excavation of Weehawken Rock Tunnels.—This subject may be dismissed in a few words, as very few features of interest were called into play. The rock was of good quality, being the sandstone typical of this part of the country. Little or no timbering was needed, there were no buildings above the tunnel to be taken care of, and large charges of powder could be used.

Work was begun on September 1st, 1904, immediately on the completion of the work on the shaft. The North and South Tunnels in this case are completely independent, as will be seen from Plate

TABLE 9.—Supplementary Analysis of Timbering, Rock Tunnel Excavation Under 32d Street, East of Cut-and-Cover Section.

Analyzed Cost of Timbering, Per Foot Run and Per Bent.

	Permanent Timbering.						Temporary Timbering.							Grand Total.			
	Lumber in feet, B. M.			Cost, in dollars.			Lumber in feet, B. M.			Cost, in dollars.				Lumber in feet, B. M.	Cost, in dollars.		
Ke	Upper Bent.	Blocking.	Total.	Lumber.	Labor.	Total.	Lower Bent.	Blocking.	Total.	Lumber.	Erection labor.	Removal labor.	Total labor.	Total.		Lumber.	Labor.	Total.
Per foot run of tunnel	274	294	568	23.75	37.50	61.25	479	193	672	29.13	28.85	8.29	37.14	66.27	1 240	52.88	74.64	127.52
Per bent, 2 ft. 6 in., center to center	685	735	1 420	59.38	93.75	153.13	11.97	483	16.80	72.81	72.13	20.73	92.86	165.67	3 100	132.19	186.61	318.80
Per cubic yard excavation	7.8	8.3	16.1	0.67	1.06	1.73	13.6	5.5	19.1	0.82	0.82	0.23	1.05	1.87	35.2	1.49	2.11	3.60
Ki																		
Per foot run of tunnel	227	164	391	16.84	12.82	29.66	186.33	42.80	229.13	9.65	10.38	9.74	20.12	29.77	620	26.49	32.94	59.43
Per bent, 3 ft. 6 in., center to center	830	601	1 431	61.56	46.88	108.44	681.25	156.50	837.75	35.31	37.97	34.09	72.06	107.37	22 69	96.87	118.94	215.81
Per cubic yard excavation	5.3	3.8	9.1	0.39	0.30	0.69	4.33	0.99	5.32	0.22	0.24	0.23	0.47	0.69	14.4	0.61	0.77	1.38
Ko																		
Per foot run of tunnel	261	408	669	28.00	29.79	57.79	350	61	411	18.45	20.83	12.16	32.99	51.44	1 080	46.45	62.78	109.23
Per bent, 3 ft. 8 in., center to center	962	1 508	24.70	103.38	110.00	213 38	1 291	227	1 518	68.16	76.92	44.59	121.51	189.67	3 988	171.54	231.50	403.04
Per cubic yard excavation	4.1	6.5	10.5	0.44	0.47	0.91	5.5	1.0	6.5	0.29	0.33	0.19	0.52	0.81	17.1	0.73	0.99	1.72

TABLE 10.—TIMBERING:—DETAILED COST OF TIMBER, LABOR, AND SUPERINTENDENCE. ROCK TUNNEL EXCAVATION UNDER 32D STREET, EAST OF CUT-AND-COVER SECTION.

	Date.	Timber Used, in Feet, B. M.			Excavation in Cubic Yards.		Cost of Timber.			Cost of Labor.	Total Cost.	Cost per Cubic Yard (Actual).			Cost per Cubic Yard (Paid for).			Cost, per 1 000 Ft., B. M., of Total Timber.		
		Main timber.	Blocking timber.	Total timber.	Actual.	Paid for.	Main.	Block.	Total.			Timber.	Labor.	Total.	Timber.	Labor.	Total.	Total timber.	Labor.	Total.
	1907	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	$\frac{h}{d}$	$\frac{i}{d}$	$\frac{j}{d}$	$\frac{h}{e}$	$\frac{i}{e}$	$\frac{j}{e}$	$\frac{h}{c}$	$\frac{i}{c}$	$\frac{j}{c}$
Ke	May.....	18 016	15 234	33 250	1 736	1 664	$810	$565	$1 375	$1 792	$3 167	$0.79	$1.03	$1.82	$0.82	$1.07	$1.90	$41 35	$53.89	$95.24
	June.....	14 048	11 528	25 576	809	698	630	457	1 087	1 576	2 663	1.34	1.95	3.29	1.55	2.25	3.81	42.50	61.62	104.12
	July	20 092	7 339	27 431	1 022	960	900	300	1 200	1 580	2 780	1.16	1.55	2.72	1.25	1.64	2.89	43.74	57.60	101.34
	August ...	6 485	2 632	9 117	743	716	200	110	400	300	700	0.53	0.40	0.94	0.57	0.41	0.98	43.87	32.90	76.77
	Sept	1 632	2 224	3 856	238	238	73	94	167	60	227	0.70	0.25	0.95	0.70	0.25	0.95	43.31	15.56	58.87
	Removal..	.....	.....	.....	.....	.....	.....	.....	.....	663	663	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Total.....	60 273	38 957	99 230	4 548	4 276	$2 703	$1 526	$4 229	$5 971	$10 200	$0.91	$1.51	$2.22	$1.00	$1.40	$2.40	$42.62	$60.19	$102.81
Ki	May.....	.....	3 537	3 537	614	527	.....	$150	$150	$100	$250	$0.24	$0.16	$0.40	$0.28	$0.19	$0.47	$42.41	$28.27	$70.68
	June.....	300	.....	300	357	259	$14	.....	14	44	58	0.04	0.12	0.16	0.05	0.17	0.22	46.66	146.33	198.33
	July	7 776	5 811	13 587	530	404	350	233	583	525	7 108	1.10	0.99	2.09	1.44	1.30	2.74	42.91	38.64	81.54
	August ...	19 712	5 702	25 414	925	890	887	220	1 107	1 018	2 125	1.20	1.10	2.30	1.24	1.14	2.38	43.56	40.06	83.61
	Sept	20 556	9 218	29 774	1 585	1 501	925	325	1 250	1 028	2 278	0.79	0.65	1.44	0.83	0.68	1.51	41.98	34.53	76.51
	Removal..	.....	.....	.....	1 669	1 407	.....	.....	.....	1 139	1 139	.....	0.68	0.68	.....	0.81	0.81	.....	.....	.....
	Total.....	48 341	24 268	72 612	5 680	4 988	$2 176	$928	$3 104	$3 854	$6 958	$0.55	$0.68	$1.23	$0.63	$0.77	$1.40	$42.75	$53.09	$95.84
Ko	May.....	4 332	8 788	13 120	250	188	$175	$366	$561	$303	$864	$2.24	$1.21	$3.45	$3.00	$1.61	$4.61	$42.76	$23.10	$65.86
	June.....	7 132	10 017	17 149	496	347	324	396	720	562	1 282	1.45	1.13	2.58	2.07	1.61	3.68	41.98	32.77	74.75
	July	3 070	200	3 270	626	606	134	10	144	156	300	0.23	0.25	0.48	0.23	0.26	0.49	44.04	47.70	91.74
	August ...	10 704	2 102	12 806	718	709	481	80	561	727	1 288	0.78	1.01	1.79	0.80	1.02	1.82	43.80	56.77	100.57
	Sept	2 400	245	2 645	396	324	108	8	116	400	516	0.29	1.01	1.30	0.36	1.23	1.59	43.85	151.23	195.08
	Removal..	.....	.....	.....	209	211	.....	.....	.....	535	535	.....	2.56	2.56	.....	2.54	2.54	.....	.....	.....
	Total.....	27 638	21 352	48 990	2 695	2 385	$1 242	$860	$2 102	$2 683	$4 785	$0.78	$1.00	$1.78	$0.88	$1.12	$2.00	$42 91	$54.75	$97.65
	Grand total	136 255	84 577	220 832	12 923	11 649	$6 121	$3 314	$9 435	$12 508	$21 943	$0.73	$0.97	$1.70	$0.81	$1.07	$1.88	$42.73	$56.65	$99.38

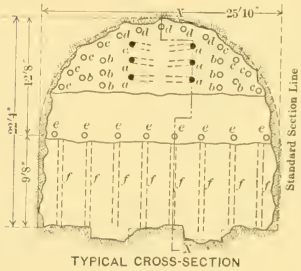
XXXIV. The procedure adopted was to drive a top heading on the center line of each tunnel and to break down the bench from this. The drilling was at first supplied with steam power from a temporary plant, as the contractor was at that time installing his permanent plant, which was finished at the end of November, 1904. At this time the rate of advance averaged $3\frac{1}{2}$ lin. ft. of full section per day of 24 hours. By the end of January the Weehawken rock tunnels were completely excavated, and by the middle of April, 1905, the excavation for the shield chambers was finished; the erection of the shields was started at the end of that month.

TABLE 11.

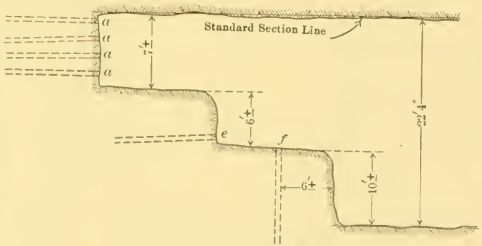
Grade.	Total No.	Rate per day.	Drilling and blasting: No.	Mucking: No.	Timbering: No.
Superintendent	1	$7.70	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{8}$
Assistant engineer	1	5.80	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{8}$
Electrician	1	3.50	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{8}$
Engineer	1	3.50	....	1	....
Signalman	1	2.00	....	1	....
Foreman	3	4.00	1	1	1
Driller	5	3.00	5	....	....
Driller's helper	5	2.00	5	....	....
Laborers	14	2.00	....	14	....
Timbermen	3	3.00	....	....	3
" helpers	4	2.00	....	....	4
Machinist	1	4.00	1	....	....
Blacksmith	2	3.50	2	....	....
" helper	2	2.00	2	....	....
Nipper	2	2.00	2	....	....
Waterboy	1	2.00	1	....	....
Total	47	....	$20\frac{1}{2}$	$17\frac{3}{8}$	$9\frac{1}{8}$

The general scheme of excavation is shown by Plate XXXIII. The bench was kept 50 or 60 ft. behind the face of the heading. The powder used was 60% Forcite. The general system of drilling was as shown in Fig. 7. The average length of hole drilled per cubic yard of excavation was 2.9 ft., as against 7.70 ft. at Manhattan; and the amount of powder used was 1.96 lb. per cu. yd., as against 1.24 lb. at Manhattan. There was little timbering. A length of about 30 or 40 ft. adjoining the Weehawken shaft was timbered, and also a shattered seam of about 17 ft. in width between Stations 262 + 10 and 262 + 27.

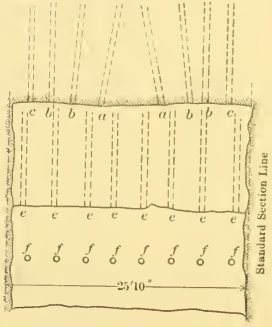
The two entirely separate tunnels gave a cross-section which was much more easily timbered than the wide flat span at Manhattan, and



TYPICAL CROSS-SECTION



LONGITUDINAL SECTION *X X*



PLAN OF BENCH AND HEADING

Kind of Rock Altered Sandstone and Trap in horizontal strata.
" " " Dynamite — 60% Forcite, average 2 lb. per cubic yard.
Drills — (Driven by compressed air), Ingersoll-Sergeant No. 3½ F 24.
Steel 1⅜" Diam. 2' long has 3¼" bits
" " " 4' " " 3⅛" "
" " " 6' " " 3 " "
" " " 8' " " 2⅞" "
" " " 10' " " 2⅝" "

6 Cut Holes *a* 10' deep
8 Side " *b* " "
8 " " *c* " "
5 Top " *d* " "
8 Lift " *e* " "
8 Bench " *f* " "

LAND TUNNELS

TYPICAL METHOD OF DRILLING USED IN THE WEEHAWKEN TUNNELS

FIG. 7.

the segmental timbering was amply strong without posts or other reinforcement.

Table 12 is a summary of the cost of excavating the Land Tunnels, based on actual records carefully kept throughout the work.

TABLE 12.—Cost of Excavation of Land Tunnels, in Dollars per Cubic Yard.

	Manhattan.	Weehawken.	Total yardage and average cost.
Cubic yards excavated	43 289	8 311	51 600
Labor.			
Surface transport	$0.49	$0.87	$0.55
Drilling and blasting	2.37	1.55	2.24
Mucking	2.49	2.08	2.42
Timbering	0.87	0.18	0.76
Total labor	$6.22	$4.68	$5.97
Material.			
Drilling	$0.15	$0.15	$0.15
Blasting	0.21	0.21	0.21
Timber	0.39	0.20	0.36
Total material	$0.75	$0.56	$0.72
Plant running	$0.76	$0.65	$0.74
Surface labor, repairs and maintenance	0.15	0.08	0.14
Field office administration	1.05	1.18	1.07
Total field charges	$8.96	$7.15	$8.64
Chief office administration	$0.34	$0.38	$0.34
Plant depreciation	0.66	1.01	0.72
Street and building repairs	0.27	....	0.23
Total average cost per cubic yard	$10.23	$8.54	$9.93

Masonry Lining of Land Tunnels.

Plates XXXII and XXXIV show in detail the tunnels as they were actually built. It will be seen that in all work, except in the Gy-East contract, there was a bench at each side of each tunnel in which the cable conduits were embedded. In Gy-East the bank of ducts which came next to the middle wall was carried below subgrade, and the inner benches were omitted.

The side-walls and subgrade electric conduits were water-proofed with felt and pitch. The water-proofing was placed on the outside of the side-walls (that is, on the neat line), and the space between

PLATE XXXIV.
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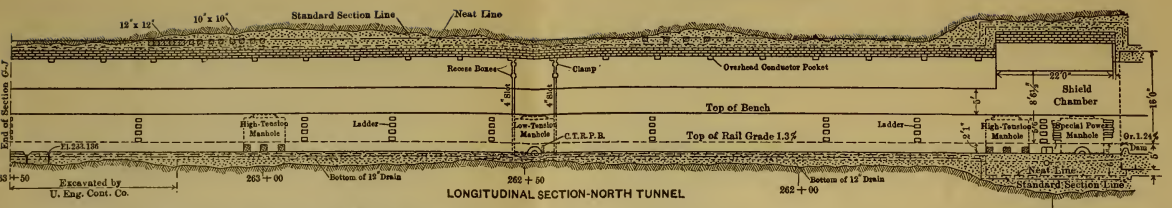
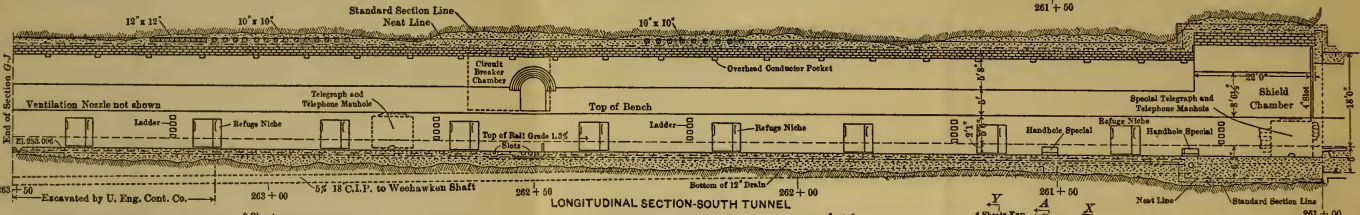
WEEHAWKEN TUNNELS

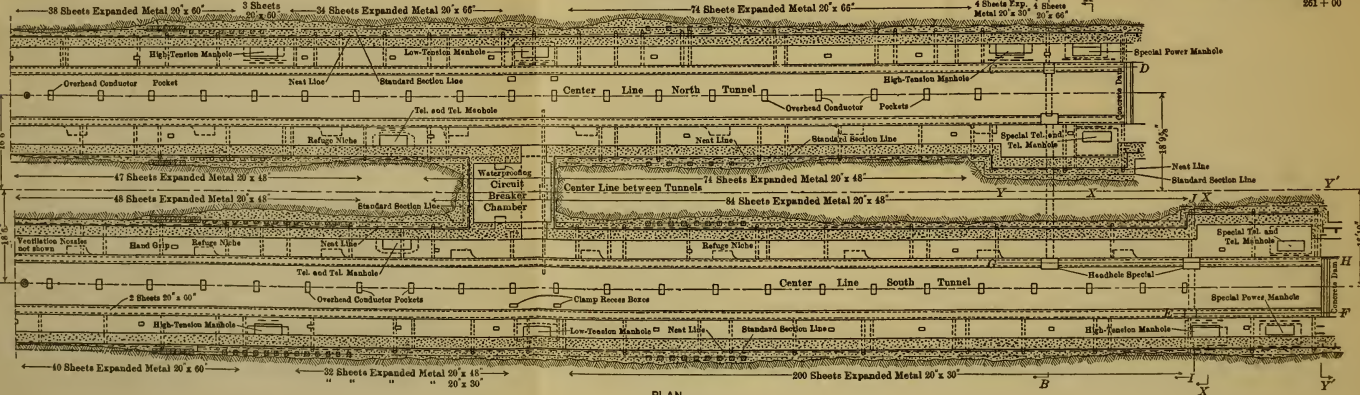
PLAN AND LONGITUDINAL SECTIONS



LONGITUDINAL SECTION-NORTH TUNNEL



LONGITUDINAL SECTION-SOUTH TUNNEL



PLAN

the rock and the water-proofing was filled with concrete. This concrete was called the "Sand-Wall."

The general sequence of building the masonry lining is shown in Fig. 8. The operations were as follows:

1.—Laying concrete for the whole height of the sand-walls, and for the floor and foundations for walls and benches up to the level of the base of the conduits;
2.—Water-proofing the side-walls, and, where there was a middle trench containing subgrade conduits, laying and water-proofing these conduits;
3.—Building concrete wall for conduits to be laid against, and, where there was a middle trench, filling up with concrete between the conduits;
4.—Laying conduits;
5.—Laying concrete for benches and middle-wall;
6.—Building haunches from top of bench to springing of brick arch;
7.—Building brick arch and part of concrete back-filling;
8.—Finishing back-filling.

The whole work will be generally described under the headings of Concrete, Brickwork, Water-proofing, and Electric Conduits.

Concrete.—The number of types and the obstructions caused by the heavy posting of the timbering made it inadvisable to use built-up traveling forms at the Manhattan side, though they were used in the Weehawken Rock Tunnels.

The specifications required a facing mixture of mortar to be deposited against the forms simultaneously with the placing of the concrete. This facing mixture was dry, about 2 in. thick, and was kept separate from the concrete during the placing by a steel diaphragm. The diaphragm was removed when the concrete reached the top of each successive layer, and the facing mixture and concrete were then tamped down together. This method was at first followed and gave good results, which was indeed a foregone conclusion, as the Weehawken shaft had been built in this way. However, it was found that as good results, in the way of smooth finish, were to be obtained without the facing mixture by spading the concrete back from the forms, so that the stone was forced back and the finer portion of the

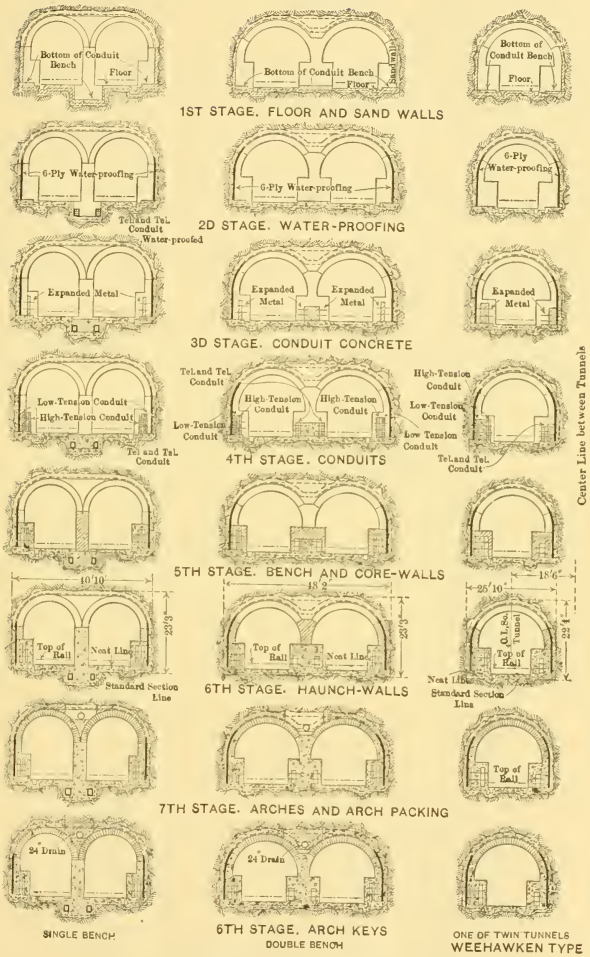
mixture came against the forms; this method was followed for the rest of the work. All corners were rounded off on a 1-in. radius by mouldings tacked to the forms. The side-bench forms were used about four times, and were carefully scraped, planed, filled at open joints, and oiled with soap grease each time they were set up. When too rough for face work they were used for sand-wall and other rough work.

The mixing was done by a No. 4 Ransome mixer, driven by 30-h.p. electric motors. The mixer at Manhattan was set on an elevated platform at the north end of the intercepting arch; that at Weehawken was placed at the entrance to the tunnels. The sand and stone were stored in bins above the mixers, and were led to the hoppers of the mixers through chutes. The hoppers were divided into two sections, which gave the correct quantities of sand and stone, respectively, for one batch. The water was measured in a small tank alongside. A "four-bag" batch was the amount mixed at one time, that is, it consisted of 4 bags of cement, $8\frac{3}{4}$ cu. ft. of sand, and $17\frac{1}{2}$ cu. ft. of broken stone, and was called a $1:2\frac{1}{2}:5$ mixture. It measured when mixed about $\frac{3}{4}$ cu. yd.

The cement was furnished to the contractor by the Railroad Company, which undertook all the purchasing from the manufacturer, as well as the sampling, testing, and storing until the contractor needed it. The Railroad Company charged the contractor $2 a barrel for this material.

The sand was required by the specifications to be coarse, sharp, and silicious, and to contain not more than 0.5% of mica, loam, dirt, or clay. All sand was carefully tested before being used. The stone was to be a sound trap or limestone, passing a $1\frac{1}{2}$-in. mesh and being retained on $\frac{3}{4}$-in. mesh. The contractor was allowed to use a coarser stone than this, namely, one that had passed a 2-in. and was retained on a $1\frac{1}{2}$-in. mesh.

The concrete was to be machine-mixed, except in cases of local necessity. The quantity of water used in the mixture was to be such that the concrete would quake on being deposited, but the engineer was to use his discretion on this point. Concrete was to be deposited in such a manner that the aggregates would not separate. It was to be laid in layers, not exceeding 9 in. in thickness, and thoroughly rammed. When placing was suspended, a joint was to be formed in



MANHATTAN TYPES

FIG. 8.

a manner satisfactory to the engineer. Before depositing fresh concrete, the entire surface on which it was to be laid was to be cleaned, washed and brushed, and slushed over with neat cement grout. Concrete which had begun to set was not to be used, and retempering was not to be allowed.

The forms were to be substantial and hold their shape until the concrete had set. The face forms were to be of matched and dressed planking, finished to true lines and surfaces; adequate measures were to be taken to prevent concrete from adhering to the forms. Warped or distorted forms were to be replaced. Plastering the face was not allowed. Rock surfaces were to be thoroughly washed and cleaned before the concrete was deposited.

These specifications were followed quite closely.

A typical working gang, as divided among the various operations, is shown below:

Superintendence.

½ Superintendent	@	$250	per month
½ Assistant engineer	"	150	" "
1 Assistant superintendent	"	150	" "

Surface Transport.

1 Foreman	@	$2.50	per day
1 Engineer	"	3.00	" "
1 Signalman	"	2.00	" "
16 Laborers	"	1.75	" "
3 Teams	"	7.50	" "

Laying.

1 Foreman	@	$4.00	per day
8 Laborers	"	2.00	" "

Forms.

1 Foreman	@	$4.50	per day
4 Carpenters	"	3.25	" "
5 Helpers	"	2.25	" "

Tunnel Transport.

¼ Foreman	@	$3.25	per day
¼ Engineer	"	3.00	" "
¼ Signalman	"	2.00	" "
4 Laborers	"	1.75	" "

Mixers.

¼ Foreman	@	$3.25	per day
2 Laborers	"	1.75	" "

The superintendent and assistant engineer looked after the brickwork and other work as well as the concrete. The surface transport gang handled all the materials on the surface, including the fetching of the cement from the cement warehouses.

The tunnel transport gang handled all materials in the tunnel, but, when the haul became too long, the gang was reinforced with laborers from the laying gang. Of the laying gang, two generally did the spading, two the spreading and tamping, and the remaining force dumped the concrete. The general cost of this part of the work is shown in Table 13.

The figures in Table 13 include the various items built into the concrete and some that are certificate extras in connection with the concrete, such as drains, ironwork and iron materials, rods and bars, expanded metal, doors, frames and fittings, etc.

Water-proofing.—According to the specifications, the water-proofing was to consist of seven layers of pitch and six layers of felt on the side-walls and a ½-in. layer of mastic, composed of coal-tar and Portland cement, to be plastered over the outside of the arches.

By the time the work was in hand, some distrust had arisen as to the efficiency of this mastic coating, and a great deal of study was devoted to the problem of how to apply a felt and pitch waterproofing to the arches. The difficulty was that there was no room between the rock and the arch or between the timber and the arch (as the case might be) in which to work. Several ingenious schemes of putting the felt on in layers, or in small pieces like shingles, were proposed and discussed, and a full-sized model of the tunnel arch was even built on which to try experiments, but it was finally decided to overcome the difficulty by leaving out the arch waterproofing altogether, and simply building in pipes for grouting through under pressure, in case it was found that the arch was wet.

As to the arch built through the length excavated by cut-and-cover on the New York side, it was resolved to water-proof that with felt and pitch exactly as the side-walls were done, the spandrel filling between the arches being raised in a slight ridge along the concrete line between tunnels in order to throw the water over to

TABLE 13.—Cost of Concrete in Land Tunnels, in Dollars per Cubic Yard.

	Manhattan.	Weehawken.	Total yardage.
Cubic yards placed	14 706½	3 723	18 429½
Labor.	**Average Cost per Cubic Yard.**		
Surface transport	$0.31	$1.43	$0.54
Superintendence and general labor at point of work	0.31	1.31	0.51
Mixing	0.52	0.56	0.53
Laying	1.38	1.45	1.39
Tunnel transport	1.30	1.47	1.34
Cleaning	0.21	....	0.17
Forms: erecting and removal	1.58	1.51	1.56
Total labor	$5.61	$7.73	$6.04
Material.			
Cement	$2.30	$2.22	$2.28
Sand	0.34	0.40	0.36
Stone	0.91	0.61	0.85
Lumber for forms	0.47	0.45	0.47
Sundry tunnel supplies	0.16	0.17	0.16
Total materials	$4.18	$3.85	$4.12
Plant running	$0.44	$0.44	$0.44
Surface labor, repairs and maintenance	0.25	1.24	0.44
Field office administration	0.50	1.72	0.75
Total field charges	$10.98	$14.98	$11.79
Plant depreciation	$0.62	$1.57	$0.81
Chief office administration	0.24	0.31	0.25
Total average cost per cubic yard	$11.84	$16.86	$12.85

Cost of Miscellaneous Items in Concrete.

	Manhattan.	Weehawken.	Average.
Cubic yards	14 706½	3 723	18 429½
Amount, in dollars	$6 184.83	$1 756.79	$7 941.62
Unit cost	0.42	0.47	0.43

the sides. The portions of arch not water-proofed were rather wet, and grouting with a 1:1 mixture was done, but only with the effect of stopping large local leaks and distributing a general dampness over the whole surface of the arch.

The 24-ft. 6-in. tunnel adjoining the Terminal Station-West was water-proofed by a surface-rendering method which, up to the present time, has been satisfactory. Generally speaking, the arches of the Land Tunnels, though not dripping with water, are the dampest parts of the whole structure from Tenth Avenue to Weehawken, and it would seem as if some form of water-proofing over these arches would have been a distinct advantage.

There was no difficulty in applying the water-proofing on the side-walls, after a little experience had been gained as to the best methods. The specifications required the sand-wall to be covered with alternate layers of coal-tar pitch and felt, seven layers of the former and six layers of the latter, the felt to be of Hydrex brand or other equally satisfactory to the engineer. The pitch was to be straight-run, coal-tar pitch which would soften at 60° Fahr., and melt at 100° Fahr., being a grade in which distillate oils, distilled from it, should have a specified gravity of 1.105. The pitch was to be mopped on the surface to a uniform thickness of $\frac{1}{16}$ in., and a covering of felt, previously mopped with pitch, was to be applied immediately. The sheets were to lap not less than 4 in. on cross-joints and 12 in. on longitudinal joints, and had to adhere firmly to the pitch-covered surface. This layer was then to be mopped, and another layer placed, and so on until all the layers were in place. This water-proofing was to extend from the bottom of the cable conduits to the springing of the brick arch. Where sub-track conduits were used, these were to be surrounded with their own water-proofing. The work was carried out as specified; the sand-walls were not rendered, but were built smooth enough to apply the water-proofing directly to them. They were dried with gasoline torches before the application of the pitch, and in very wet sections grooves were cut to lead the water away.

The first attempts were with the felt laid in horizontal strips. This ended very disastrously, as the pitch could not sustain the weight of the felt, and the whole arrangement slipped down the wall. The felt was then laid vertically, being tacked to a piece of horizontal scantling at the top of the sand-wall and also held by a row of planks

braced against it at about half its height. A layer of porous brick was laid as a drain along the base of the water-proofing, covered by a single layer of felt to prevent it from becoming choked with concrete.

The water-proofing of the sub-track conduits was troublesome, as the numerous layers and the necessity for preserving the proper laps in both directions between adjacent layers made the whole thing a kind of Chinese puzzle. Various modifications, to suit local conditions, were made from time to time. Conduits outside the general outline of the tunnel are difficult to excavate, to lay, and to water-proof, and should be avoided wherever possible.

The usual force in water-proofing consisted of a foreman, at $3.50 per day, and nine laborers at $1.75 per day. These men not only laid the water-proofing, but transported the materials, heated the pitch, and cut up the rolls of felt. In general, two men transported material, one tended the heater, and the other six worked in pairs, two preparing the surface of the concrete sand-wall, two laying pitch, and two laying felt.

The cost of the water-proofing operation was about as shown in Table 14.

TABLE 14.—Cost of Water-Proofing, in Dollars per Square Foot.

	Manhattan.	Weehawken.	Total.
Square feet covered	47 042	13 964	60 736
	Average cost per square foot.		
Labor	$0.07	$0.07	$0.07
Material	0.12	0.09	0.11
Total field charges	$0.19	$0.16	$0.18
Chief office and plant depreciation	0.01	0.03	0.02
Total average cost	$0.20	$0.19	$0.20

Brickwork in Arches.—Owing to the heavy timbering, the brickwork at Manhattan was interfered with to a considerable extent, and the gang was always kept at work at two or more places. The work was carried up to a point where it was necessary to back-fill, or prop or cut away encroaching timbers, and then the men were moved to another place while this was being done.

The centers were set up in sets of seven, spaced 4 ft. apart. Two

14-ft. lengths of 3 by 4-in. yellow pine lagging were used with each set of ribs, with 24 by 8-in. block lagging in the crown.

All centers were set $\frac{1}{4}$ in. high, to allow for settlement, except in the 24-ft. 6-in. span, in which they were set $\frac{1}{2}$ in. high. This proved ample, the average settlement of the ribs being 0.01 ft. and of the masonry, 0.003 ft. In the 24-ft. 6-in. span the ribs were strengthened with 6 by 6-in. blocking and 12 by 12-in. posts to subgrade. Great trouble was here encountered with encroaching timbering, due to the settlement of the wide flat span. Grout pipes were built in, as previously mentioned.

Each mason laid an average of 0.535 cu. yd. of brickwork per hour, or 4.28 cu. yd. per day. The number of bricks laid per mason per hour was 218, or 1 744 per day.

The bricks were of the best quality of vitrified paving brick, and were obtained from the Jamestown Brick Company, of Jamestown, N. Y. The average size was $8\frac{3}{4}$ by $3\frac{5}{16}$ by $2\frac{7}{16}$ in.; the average number per cubic yard of masonry was 408, the arches being from 19 ft. to 24 ft. 6 in. in span and from 22 to 27 in. thick. The joints were $\frac{3}{16}$ in. at the face and averaged $\frac{9}{16}$ in. through the arch.

The proportions for mortar were 1 of cement and $2\frac{1}{2}$ of sand. One cubic yard of masonry was composed of 73.5% brick and 26.5% mortar. The volume of the ingredients in a four-bag batch was 12.12 cu. ft., and the resulting mixture was 9.54 cu. ft. The number of barrels of cement was 0.915 per cu. yd. of masonry, and about 17.7% of the mortar made was wasted. The average force employed was:

Laying.

1 Foreman	@	$8.00	per day
4 Layers	"	6.00	" "
8 Tenders	"	2.00	" "
2 Mixers	"	2.00	" "

Forms.

1 Foreman	@	$4.50	per day
4 Carpenters	"	3.50	" "
5 Helpers	"	2.25	" "

Transport.

$\frac{1}{4}$ Hoist engineer	@	$3.00	per day
$\frac{1}{4}$ Signalman	"	2.00	" "
4 Laborers	"	2.00	" "

For materials, the following prices prevailed:

Cement, $2.00 per bbl.,
Sand, $0.90 to $1.00 per cu. yd.,
Brick, $16.00 per thousand, delivered at yard,
Centers, $26.00 each,
Lagging, $45.00 per 1 000 ft. B. M.

The cost of the brickwork is given in Table 15.

TABLE 15.—Cost of Brickwork.

	Manhattan.	Weehawken.	Total.
Cubic yards placed	4 137	790	4 927
Labor.	**Average Cost per Cubic Yard.**		
Surface transport	$0.35	$1.19	$0.48
Superintendent and general labor at point of work	0.17	0.04	0.16
Laying and mixing	2.58	3.20	2.60
Forms: erection and removal	2.62	0.32	2.25
Tunnel transport	1.19	1.12	1.18
Total labor	$6.91	$5.87	$6.75
Material.			
Brick	$6.56	$6.56	$6.56
Cement	1.76	1.75	1.76
Sand	0.20	0.28	0.22
Forms	0.92	0.98	0.93
Overhead conductor pockets	0.15	0.09	0.13
Total material	$9.59	$9.66	$9.60
Plant running	$0.55	$0.30	$0.51
Surface labor, repairs and maintenance	0.36	1.30	0.51
Field office administration	0.55	0.88	0.60
Total field charges	$17.96	$18.01	$17.97
Chief office administration	$0.60	$0.66	$0.61
Plant depreciation	0.35	0.64	0.39
Total average cost per cubic yard	$18.91	$19.31	$18.97

In Table 16 the cost of grout is expressed in terms of barrels of cement used, because in the schedule of prices attached to the contract, that was the unit of payment for grout.

TABLE 16.—Cost of Grout Over Arches in Land Tunnels.
Cost, in Dollars per Barrel of Cement Used.

	Manhattan. (Gy-East only.)	Weehawken.	Total.
Barrels used	3 000½	261½	3 262
	Average Cost per Barrel of Cement Used.		
Labor	$0.55	$0.46	$0.53
Material	2.30	2.25	2.28
Field office administration	0.08	0.06	0.08
Plant and supplies	0.10	0.07	0.09
Total field charges	$3.03	$2.84	$2.98
Chief office and plant depreciation	0.21	0.22	0.22
Total average cost	$3.24	$3.06	$3.20

Vitrified Earthenware Conduits for Electric Cables.—The general drawings will show how the ducts were arranged, and that manholes were provided at intervals. They were water-proofed, in the case of those embedded in the bench, by the general water-proofing of the tunnels, which was carried down to the level of the bottom of the banks of ducts; and in the case of those below subgrade, by a special water-proofing of felt and pitch wrapped around the ducts themselves.

The portion of wall in front of the ducts was bonded to that behind by bonds, mostly of expanded metal, passing between the ducts. Examples of the bonding will be seen in the drawings.

The joints between successive lengths of 4-way and 2-way ducts were wrapped with two thicknesses of cotton duck, 6 in. wide, those of single-way ducts were not wrapped, but plastered with cement mortar. The ducts were laid on beds of mortar, and were made to break joints at top and bottom and side to side with the adjacent ducts. They were laid with a wooden mandrel; a square leather washer at the near end acted as a cleanser when the mandrel was pulled through.

The specifications required the ducts to be laid at the same time as the concrete and be carried up with it, but this was found to be a very awkward operation, as the tamping of the concrete and the

walking of men disturbed the ducts, especially as the bonds lay across them. It was resolved, therefore, to build the portion of the wall behind the ducts first, with the bonds embedded in it at the proper heights and projecting from it, then to lay up the banks of ducts against this wall, bending the bonds down as they were reached, and finally, after all the ducts were in, to lay the concrete in front of and over the top of the ducts. Several detailed modifications of this general scheme were followed at one time or another when necessary or advisable.

The laying of ducts below subgrade was not complicated by the presence of bonds, the water-proofing caused the trouble here, as before described.

The specifications called for a final rodding after completion. A group of the apparatus used in this process is shown in Fig. 1, Plate XXXV; the various parts are identified by the following key:

KEY TO FIG. 1, PLATE XXXV.

1.—4-way duct, for telephone and telegraph cables,
2.—2-way duct, for telephone and telegraph cables,
3.—1-way duct, for high- and low-tension cables,
4.—Plug for closing open ends of ducts,
5.—Plug for closing open ends of ducts in position,
6, 7, and 8.—Cutters for removing obstructions,
9.—Hedgehog cutter for removing grout in ducts,
10.—Rodding mandrel for multiple ducts,
11.—Laying mandrel,
12.—Rodding mandrel, with jar-link attached,
13.—Laying mandrel,
14 and 15.—Rubber-disk cleaners, used after final rodding,
16 and 17.—Sectional wooden rods used for rodding,
18.—Section of iron rods used for rodding.
19.—Jar-link,
20.—Cotton duck for wrapping joints of multiple ducts,
21.—Hook for pulling forward laying mandrel,
22.—Top view of trap for recovering lost or broken rods left in ducts.

Ordinary $\frac{3}{4}$-in. gas pipe was used for the rod, and a cutter with rectangular cross-section and rounded corners was run through ahead of the mandrel: following the cutter came a scraper consisting of

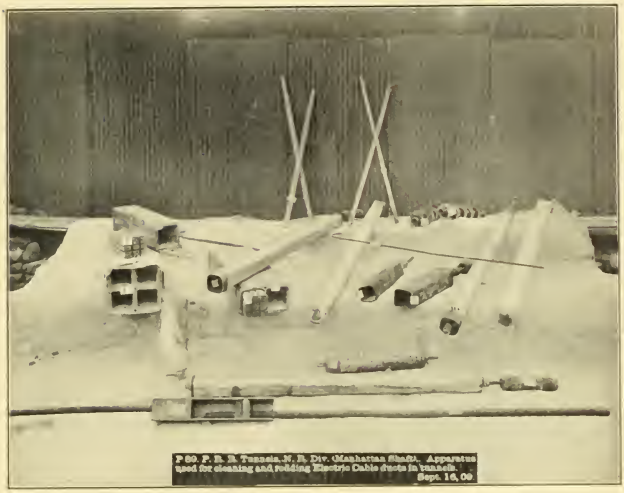

P 60. P. R. R. Tunnels, N. R. Div. (Manhattan Shaft). Apparatus used for cleaning and folding Electric Cable ducts in tunnels.
Sept. 16, 06

FIG. 1.

A. 39. P. R. R. Tunnels, N. R. Div. Sect. Gy. Showing Shield, (South Manhattan) in Hudson River Silt with one door of Shield open.
Aug. 24, 06.

FIG. 2.

several square leather washers, of the size of the ducts, spaced at intervals on a short rod. The mandrel itself was next put through, three or four men being used on the rods. All the ducts in a bank were thus rodded from manhole to manhole. When a duct was rodded it was plugged at each end with a wooden plug. A solid wooden paraffined plug was used at first, but afterward an expansion plug was used.

Very little trouble was met in rodding the power conduits, except for a few misplaced ducts, or a small mound of mortar or a laying mandrel left in. At such points a cut was made in the concrete and the duct replaced.

In the subgrade telephone and telegraph ducts east of the Manhattan Shaft, much trouble was caused by grout in the ducts. The mandrel and cutters were deflected and broke through the web of the ducts rather than remove this hard grout. Trenches had to be cut from the floor to the top of the water-proofing, the latter was then cut and folded back, and the ducts replaced. To do this, a number of ducts had to be taken out to replace the broken ones and get the proper laps. The water-proofing was then patched and the concrete replaced. This grout had not penetrated the water-proofing, but had got in through the ends of the ducts where they had not been properly plugged and protected. The duct gang, both for laying and rodding, generally consisted of

1 Foreman, at $3.50 per day,
and 9 laborers, at $1.75 per day.

When laying: 4 men were laying, 2 men mixing and carrying mortar, and 3 were transporting material. When rodding: 4 men were rodding, 2 men at adjacent manholes were connecting and disconnecting cutters and mandrels, 1 was joining up rods, and 2 men assisting generally.

The cost of this work is shown in Table 17.

Transportation and Disposal.

The track on the surface and in the tunnels was of 20-lb. rails on a 2-ft. gauge.

The excavation was handled in scale-boxes carried on flat cars, and the concrete in 1¼-cu. yd. mining cars dumping either at the side or end.

TABLE 17.—Cost of Conduit Work.

	Manhattan.	Weehawken.	Total.
Duct feet	115 962	35 155	151 117
	Average Cost per Duct Foot.		
Labor	$0.035	$0.032	$0.034
Material	0.043	0.052	0.045
Total field charges	0.078	0.084	0.079
Chief office and plant depreciation	0.005	0.008	0.006
Total average cost	$0.083	$0.092	$0.085

When the haulage was up grade, 6 by 6-in. Lidgerwood hoisting engines, with 10-in. single friction drums, and driven by compressed air from the high-pressure lines, were used. Down grade, cars were moved and controlled by hand.

The muck which came through the shaft at Manhattan was dumped into hopper bins on the surface and thence loaded into trucks at convenience. At the open cut, the muck was dumped into trucks direct. The trucking was sublet by the contractor to a sub-contractor, who provided trucks, teams, and trimmers at the pier. At Weehawken, arrangements were made with the Erie Railroad which undertook to take muck which was needed as fill. The tunnel cars, therefore, were dumped directly on flat cars which were brought up to a roughly made platform near the shaft.

The hoisting at Manhattan was by derrick at Tenth Avenue and the open cut, and by the elevator at the Manhattan Shaft. At Weehawken, all hoisting was done by the elevator in the shaft.

The sand and stone were received at the wharves by scows. At Manhattan, these materials were unloaded on trucks by an overhead traveler, and teamed to the shaft, where they were unloaded by derricks into the bins. At Weehawken, they were unloaded by an orange-peel grab bucket, loaded into cars on the overhead trestle, transported in these to the top of the shaft, and discharged into the bins.

The cement at Manhattan was trucked from the Company's warehouse, at Eleventh Avenue and 38th Street, to the shaft, where it was

put into a supplementary storage shed at the top of the shaft, whence it was removed to the mixer by the elevator when needed. At Weehawken, it was taken on flat cars directly from the warehouse to the mixer.

Lighting.

Temporarily and for a short time at the start, kerosene flares were used for light until replaced by electric lights, the current for which was furnished by the contractor's generators, which have been described under the head of "Power Plant."

The lamps used along the track were of 16 c.p., and were protected by wire screens; these were single, but, wherever work was going on, groups of four or five, provided with reflectors, were used.

Pumping.

Two pumps were installed at the Manhattan Shaft. They had to handle the water, not only from the rock tunnels, but also from those under the river. One was a Deane compound duplex pump, having a capacity of 500 gal. per min., the other, a Blake pump, of 150 gal. per min. They were first driven by steam direct from the power-house, but compressed air was used later. When the power-house was shut down, an electrically-driven centrifugal pump was used. This was driven by a General Electric shunt-wound motor, Type C-07½, with a speed of 1 250 rev. per min. at 250 volts and 37.5 amperes (10 h.p.) when open, and 22.9 amperes (6 h.p.) when closed, and had a capacity of 450 gal. per min. To send the water to the shaft sump during the construction, small compressed-air Cameron pumps, of about 140 gal. per min., were used.

At the Weehawken shaft two pumps were used; these dealt with the water from the Bergen Hill Tunnels as well as that from the Weehawken Tunnels. At first a Worthington duplex pump having a capacity of about 500 gal. per min. was used. Later, this was replaced by a General Electric shunt-wound motor, Type O-15, with a speed of 925 rev. per min. at 230 volts and 74 amperes (20 h.p.) when open, and 38.5 amperes (10 h.p.) when closed. Its capacity was 240 gal. per min. During the progress of the construction, the water was pumped from the working face to the shaft by small Cameron pumps similar to those used at Manhattan. When the work was finished,

a subgrade reversed-grade drain carried the water to the shaft sump by gravity.

The work in the Manhattan Land Tunnels was practically finished by May 1st, 1908, though the ventilating arrangements and overhead platform in the intercepting arch were not put in until after the River Tunnel concrete was completed, so that the work was not finished until September, 1909.

The Weehawken Land Tunnels work was finished in July, 1907, but the benches and ventilating arrangements in the Weehawken Shaft were not put in until after the completion of the Bergen Hill Tunnels, and so were not finished until August, 1909.

The reinforced concrete wall around the Weehawken Shaft, together with the stairs from the bench level of the shaft to the surface, was let as a separate contract; the work was started on September 15th, 1909, and finished by the end of December, 1909.

River Tunnels.

The River Tunnel work, from some points of view, has the most interest. It is interesting because it is the first main line crossing of the formidable obstacle of the Hudson River, and also by reason of the long and anxiously discussed point as to whether, in view of the preceding experiences and failures to construct tunnels under that river, foundations were needed under these tunnels to keep them from changing in elevation under the action of heavy traffic.

The River Tunnels here described start on the east side of the shield chambers on the New York side and end at the east side of the shield chambers on the New Jersey side. They thus include the New York and exclude the New Jersey shield chambers, the reason for such discrimination being that the New York shield chambers are lined with cast iron while those on the New Jersey side are of the typical rock section type, as already described. The design of the tunnels and their accessories will be first described, then will come the construction of the tunnels as far as the completion of the metal lining, followed by a description of the concrete lining and completion of the work.

Design of Metal Lining.

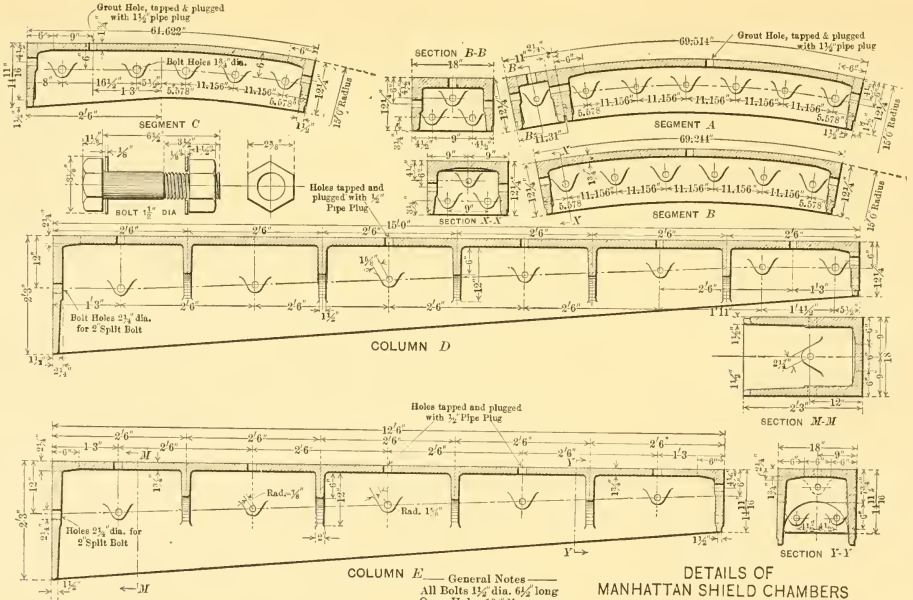
New York Shield Chambers.—The shield chambers may be seen on Plate XXXII, previously referred to, which shows the junction of the iron-lined tunnels and the shield chambers. They consist of two

iron-lined pieces of tunnel placed side by side, with semi-circular arches and straight side-walls. The segments of the arch are made to break joint with one another by making the side-wall or column castings of two different heights, as shown in Fig. 9. The length of each ring is 18 in.

The reason for the adoption of this type of construction was the necessity for keeping the width of the permanent structure within the 60-ft. width of the street. The length of this twin structure is 28.5 ft., and the weight of the metal in it is as follows:

19 long-column arch rings at 22 802 lb.	433 238 lb.
19 short-column arch rings at 23 028 lb.	437 532 "
Total weight	870 770 lb.

General Type of River Tunnel Lining.—The main ruling type adopted for the tunnels under the Hudson River, and in the soft water-bearing ground for some distance on the shoreward side of the river lines, consists of two parallel metal-lined tunnels, circular in cross-section, each tunnel being 23 ft. outside diameter, and the two tunnels 37 ft. apart from center to center, as shown on Fig. 10. The metal lining is of cast iron (except for a few short lengths of cast steel) and of the usual segmental type, consisting of "Rings" of iron, each ring being 2 ft. 6 in. in length, and divided by radial joints into eleven segments, or "Plates," with one "Key," or closing segment, having joints not radial but narrower at the outside circumference of the metal lining than at the inside. The whole structure is joined, segment to segment, and ring to ring, by mild-steel bolts passing through bolt holes in flanges of all four faces of each segment. The joints between the segments are made water-tight by a caulking of sal-ammoniac and iron borings driven into grooves formed for the purpose on the inner edges of the flanges. The clearances between the bolts and the bolt holes are also made water-tight by using grummets or rings of yarn smeared with red lead, having a snug fit over the shank of the bolt and placed below the washer on either end of each bolt. When passing through ground more or less self-sustaining, the space outside the iron lining (formed by the excavation being necessarily rather larger than the external diameter of the lining itself) was filled with grout of 1:1 Portland cement and sand forced by air



—— General Notes ——
All Bolts 1½" dia. 6½" long
Open Holes 1⅝" dia. except where otherwise noted.
All Fillets ¾" Radius

FIG. 9.

pressure through grout holes in each segment. These holes were tapped, and were closed with a screw plug before and after grouting.

Having thus stated in a general way the main ruling features of the design, a detailed description of the various modifications of the ruling type will be given.

TYPICAL CROSS-SECTION OF RULING DESIGN OF METAL-LINED SHIELD-DRIVEN TUNNELS

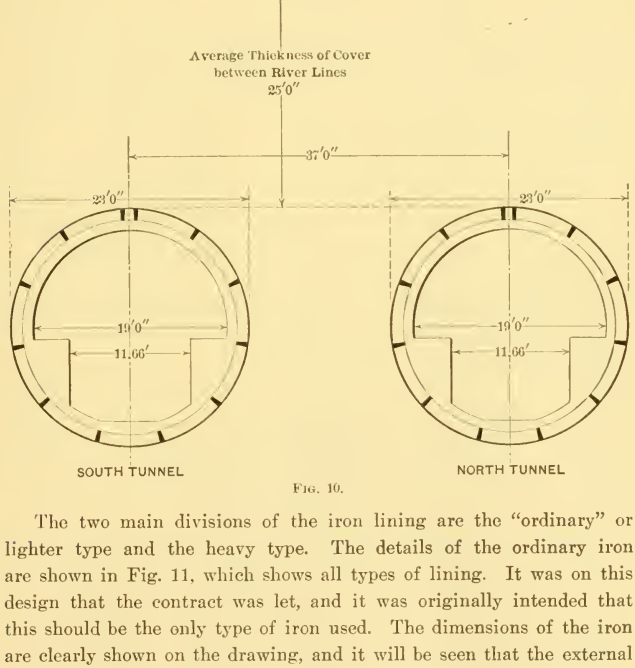


FIG. 10.

The two main divisions of the iron lining are the "ordinary" or lighter type and the heavy type. The details of the ordinary iron are shown in Fig. 11, which shows all types of lining. It was on this design that the contract was let, and it was originally intended that this should be the only type of iron used. The dimensions of the iron are clearly shown on the drawing, and it will be seen that the external diameter is 23 ft., the interior diameter, 21 ft. 2 in., the length of each ring, 2 ft. 6 in., and the thickness of the iron skin or web, 1½ in. The bolt holes in the circumferential flanges are evenly spaced through the

circle, so that adjacent rings may be bolted together in any relative position as regards the radial joints, and, as a matter of fact, in the erection of the tunnel lining, all the rings "break joint," with the exception of those at the bore segments, as will be described later. This type of iron, when the original type was modified, came to be known as the ordinary pocketless iron; that is, the weight is of the ordinary or lighter type, in contradistinction to the heavier one, which later supplanted it, and the caulking groove runs along the edges of the flanges and does not form pockets around the bolt holes, as did the groove in a later type.

Each ring is made up of eleven segments and a key piece. Of these, nine have radial joints at both ends, and are called *"A"* segments; two, called *"B"* segments, have a radial joint at one end and a non-radial joint at the other. The non-radial joint is placed next to the key, which is 12.25 in. wide at the outside circumference of the iron and 12.50 in. wide at the inside.

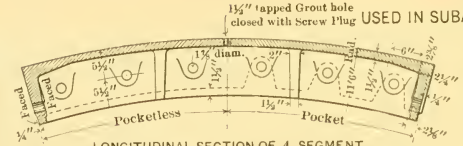
The web is not of uniform thickness. The middle part of each *A* and *B* segment is $1\frac{1}{2}$ in. thick; at the distance of 6 in. from the root of each flange, the thickness of web begins to increase, so that at the root it is $2\frac{3}{8}$ in. thick. The web of the key plate is $1\frac{3}{4}$ in. thick.

The bolts are of mild steel, and are $1\frac{1}{2}$ in. in diameter; there are 67 in one circumferential joint and 5 in each radial joint. As there are 12 such radial joints, there are altogether 60 bolts in the cross-joints, making a total of 127 bolts per ring.

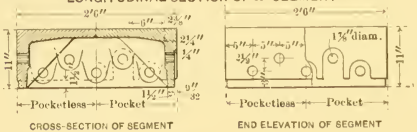
This original type of ordinary iron was modified for a special purpose as follows: It was known that for some distance on either side of the river, and especially at Weehawken, the tunnels would pass through a gravel formation, rather open, and containing a heavy head of water. It was thought that, by carrying the caulking groove around the bolt holes, it would be possible to make them more water-proof than by the simple use of the red-leaded grummets. Hence the "Pocket Iron" was adopted for this situation, the name being derived from the pocket-like recess which the caulking groove formed when extended around the bolt hole. The details of this lining are shown on Fig. 11, and the iron (except for the pockets) is exactly like the pocketless type.

On the New York side, in both North and South Tunnels, two short lengths were built with cast-steel lining. This was done where

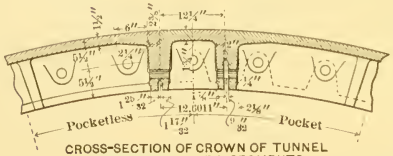
DETAILS OF ALL TYPES OF METAL LININGS USED IN SUBAQUEOUS SHIELD-DRIVEN TUNNELS



LONGITUDINAL SECTION OF *A* SEGMENT



CROSS-SECTION OF SEGMENT — END ELEVATION OF SEGMENT



CROSS-SECTION OF CROWN OF TUNNEL SHOWING ENDS OF *B* SEGMENTS AND KEY

ORDINARY METAL LINING

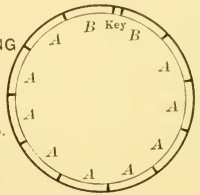
(CAST IRON AND CAST STEEL)

Note:

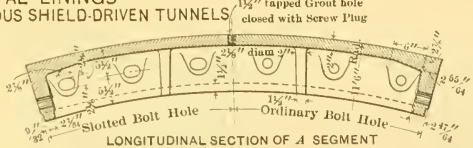
The Slotted Bolt hole type of Lining, used to reduce "roll" of Iron, was made in "Ordinary" type of Metal Lining as well as in the "Heavy" type.

The "Pocket" type of Caulking groove was used only in the "Ordinary" type of Metal Lining.

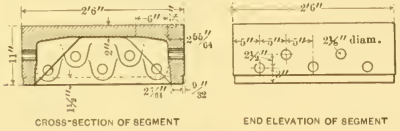
Cast Steel Lining of the "Ordinary" type was used at the point of transition from Rock to Silt on the New York side and also in passing under the New York river bulkhead wall.



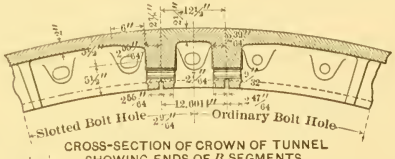
ASSEMBLY OF RING



LONGITUDINAL SECTION OF *A* SEGMENT



CROSS-SECTION OF SEGMENT — END ELEVATION OF SEGMENT



CROSS-SECTION OF CROWN OF TUNNEL SHOWING ENDS OF *B* SEGMENTS AND KEY

HEAVY CAST-IRON LINING

END ELEVATION OF TAPER RING

¾ and 1 Taper Rings were also used

FIG. 11.

unusual stresses were expected to come on the lining, namely, at the point where the invert passed from firm ground to soft, and also where the tunnels passed under the heavy river bulkhead wall.

The design was precisely the same as for the ordinary pocketless iron, and Fig. 11 shows the details. After the tunnels had entered into the actual under-river portion, several phenomena (which will be described later) led to the fear that the tunnels, being lighter than the semi-liquid mud they displaced, might be subject to a buoyant action, and therefore a heavier type of lining was designed. The length of ring, number of bolts, etc., were just the same as for the lighter iron, but the thickness of the web was increased from 1½ to 2 in., the thickness of the flanges was proportionately increased, and the diameter of the bolts was increased from 1½ to 1¾ in. This iron was all of the pocketless type, shown in Fig. 11. Table 18 gives the weights of the various types of lining.

TABLE 18.—Weights of Tunnel Lining, Diameter and Weights of Bolts, etc.

Reference No.	Type of Lining.	Weight of one "A" Segment, in pounds.	Weight of one "B" Segment, in pounds.	Weight of one key, in pounds.	Weight of one complete ring, in pounds.	Diameter of bolts, in inches.	Weight of 1 bolt, nut, and 2 washers, in pounds.	Weight of bolts, nuts, and washers per ring, in pounds.	Total weight of one ring (segments and bolts), in pounds.
1	Ordinary cast iron without caulking pockets..	2 063	2 068	480	23 183	1½	6.62	840.7	24 024
2	Ordinary cast iron with caulking pockets.....	2 038	2 043	469	22 897	1½	6.62	840.7	23 738
3	Ordinary cast steel without caulking pockets..	2 247	2 252	522	25 249	1½	6.62	840.7	26 090
4	Heavy cast iron without caulking pockets.....	2 579	2 584	606	28 985	1¾	10.50	1 333.5	30 319

Weights of Various Types of Lining per Linear Foot of Tunnel.

Reference No.	Type of Lining.	Weights of complete rings (segments only), in pounds.	Weights of bolts, nuts, and washers, in pounds.	Weights of segments and bolts in tunnel complete, in pounds.
1	Ordinary cast iron without pockets.....	9 273.0	336.3	9 609.6
2	Ordinary cast iron with pockets	9 158.8	336.3	9 495.2
3	Ordinary cast steel without pockets	10 099.6	336.3	10 436.0
4	Heavy cast iron without pockets.....	11 594.0	533.4	12 127.6

The weights in Table 18 are calculated by assuming cast iron to weigh 450 lb. per cu. ft., and cast steel 490 lb. In actual practice the "ordinary" iron was found to weigh a little more than the weights given, and the "heavy" a little less.

The silt in the sub-river portion averaged about 100 lb. per cu. ft., so that the weight of the silt displaced by the tunnel was about 41 548 lb. per lin. ft.

Taper Rings.—In order to pass around curves (whether horizontal or vertical), or to correct deviation from line or grade, taper rings were used; by this is meant rings which when in place in the tunnels were wider than the standard rings, either at one side (horizontal tapers or "Liners"), or at the top ("Depressors"), or at the bottom ("Elevators").

In the original design a ½-in. taper was called for, that is, the wide side of the ring was ½ in. wider than the narrow side, which was of the standard width of 2 ft. 6 in. As a matter of fact, during construction, not only ½-in., but ¾-in. and 1-in. tapers were often used.

These taper rings necessitated each plate having its own unalterable position in the ring, hence each plate of the taper ring was numbered, so that no mistake could be made during erection.

The taper rings were made by casting a ring with one circumferential flange much thicker than usual, and then machining off this flange to the taper. This was not only much cheaper than making a special pattern for each plate, but made it possible to see clearly where and what tapers were used in the tunnel.

Taper rings were provided for all kinds of lining (except the cast steel), and the lack of taper steel rings was felt when building the steel-lined parts of the tunnel, as nothing could be done to remedy deviations from line or grade until the steel section was over and cast iron could again be used. Table 19 gives the weights of the different kinds of tapers used.

TABLE 19.—Weights of Cast-Iron Taper Rings, in Pounds per Complete Ring.

Classification.	Weight of cast iron per complete ring, in pounds.
Ordinary pocketless ½-in. taper	23 767.7
" " 1- " "	24 352.4
" pocket ½- " "	23 481.7
Heavy pocketless ½-in. taper	29 564.8
" " ¾- " "	29 854.7
" " 1- " "	30 144.6

Cast-Steel Bore Segments and Accessories.—The following feature of these tunnels is different from any hitherto built. It was the original intention to carry the rolling load independent of the tunnel, or to assist the support of the silt portion of the structure by a single row of screw-piles, under each tunnel, and extending down to firmer ground than that through which the tunnels were driven. Therefore, provision had to be made whereby these piles could be put down through the invert of the tunnel with no exposure of the ground.

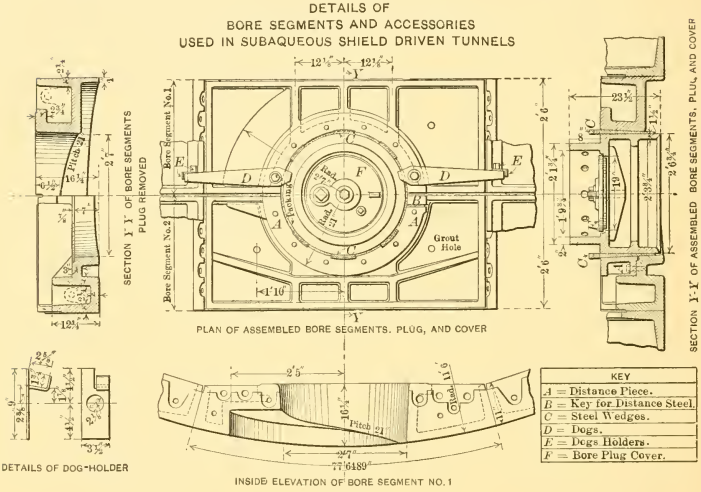


FIG. 12.

This provision was afforded by the "Bore Segments," which are shown in detail in Fig. 12. There are two segments, called No. 1 and No. 2, respectively. These two segments are bolted together in the bottom of two adjacent rings, and thus form a "Pile Bore." As the piles were to be kept at 15-ft. centers, and as the tunnel rings were 2 ft. 6 in. in length, it will be seen that, between each pair of bore-segment rings, there came four "Plain" rings. The plain rings were built up so that the radial joints broke joint from ring to ring, but with the bore-segment rings this could not be done, without unnecessarily adding to the types of segments.

The bore segments were made of cast steel, and were quite complicated castings, the principle, however, was quite simple. The segments provided an opening just a little larger than the shaft of the pile, the orifice being 2 ft. 7 in. in diameter at the smallest (lowest) point, while the shaft of the pile was to be 2 ft. 5¼ in. In order to allow of the entry of the screw-blade or helix of the pile, a slot was formed in the depth of Bore Segment No. 1, so that, when a pile was put in position above the bore, the blade, when revolved, would enter the slot and thus pass under the metal lining, although the actual orifice was only slightly larger than the pile shaft.

The wall of the pile orifice in Segment No. 2 was made lower than that in No. 1 so as to allow the blade to enter the slot in Segment No. 1. When the pile is not actually in process of being sunk, this lower height in No. 2 is made up with the removable "distance piece." This had a tongue at one end which engaged in a recess cast to take it in Segment No. 2 and was held in place by a key piece at the other end of the distance piece. Details of the distance piece and key are shown in Fig. 12.

The flanges around the pile bore were made flat and furnished with twelve tapped holes, six in Segment No. 1 and six in Segment No. 2, for the purpose of attaching the permanent arrangements in conjunction with which the pile was to be attached to the track system, independently of the tunnel shell, or directly to the tunnel. It was never decided which of these alternatives would be used, for, before this decision was reached, it was agreed that, at any rate for the present, it was better not to put down piles at all.

To close the bore, the "Bore Plug" was used. This is shown on Fig. 12. It was of cast steel, and was intended to act as a permanent point of the screw-pile, that is, the blade section was to be attached to the bore plug, the distance piece and key were to be removed, and the pile was to be rotated until the blade had cleared the slot; the distance piece and key were then to be replaced and sinking resumed.

The plug was held in place against the pressure of the silt by the two "dogs," while the dogs themselves were attached to the tunnel, as shown in Fig. 12. The ends of the dogs, which rested on the flanges of the metal lining of the tunnel, were prevented from being knocked off the flanges (and thus releasing the plug) by steel clips.

It was expected that it might be desirable to keep the lower end

of the piles open during their sinking, so that the bore plugs were not made permanently closed, but a seating was formed on the inner circumference of the plug, and on the seating was placed the "Plug Cover," made of cast iron, 18¾ in. in diameter and 3 in. thick, furnished with a lug for lifting and a 3-in. tapped hole closed by a screw-plug, through which any soundings or samples of ground could be taken prior to sinking the piles. This plug cover was held in place by a heavy steel "Yoke" under it, which engaged on the under side of the flange, on top of which the cover was set. The yoke was attached to the cover by a 1¾-in. tap-bolt, screwed into the yoke and passing through a 2-in. hole bored in the center of the cover. This rather peculiar mode of attaching the cover was adopted so that the cover could be removed by taking off the nut of the yoke, in case it was desired to open the end of the pile during the process of sinking.

The plug was a fairly close fit at the bottom of the orifice, that is, at the outside circumference of the tunnel, where the bore was 2 ft. 7 in. in diameter and the plug 2 ft. 6¾ in., but at the top of the bore-segment there was more clearance, as the plug was cylindrical while the bore tapered outward. To fill this space, it was intended that steel wedges should be used while the shield was being driven, so that they would withstand the crushing action of the thrusting shield, and, when the shield was far enough ahead, that they should be removed and replaced by hardwood wedges. This method was only used in the early weeks of the work; the modification of not using the shield-jacks which thrust against the bore segments was then introduced, and the wooden wedges were put in, when the bore plugs were set in place, and driven down to the stage of splitting.

When it was resolved not to sink the screw-piles, the bores had to be closed before putting in the concrete lining. This was done by means of the covers shown in Fig. 13. The bore plug and all its attachments were removed, and the flat steel cover, 2 in. thick and with stiffening webs on the under side, was placed over the circular flanges of the pile bore. The cover was attached to the bore segments by twelve 1½-in. stud-bolts, 6 in. long, in the bolt holes already mentioned as provided on these flanges.

When these were in place, with lead grummets under the heads of the bolts, and the grooves caulked, the bore segments were water-

tight, except in Bore Segment No. 2, at the joint of the distance piece; and, to keep water from entering here, this segment was filled to the level of the top of the flanges with 1 : 1 Portland cement mortar.

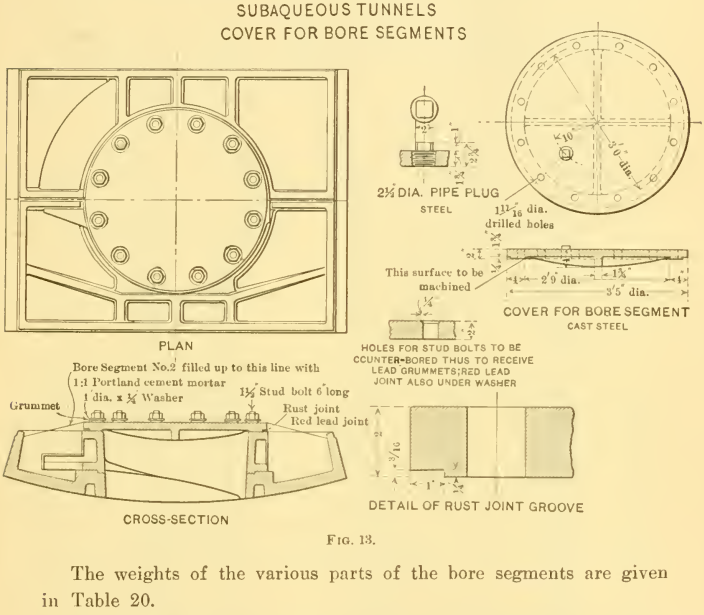


FIG. 13.

The weights of the various parts of the bore segments are given in Table 20.

TABLE 20.—WEIGHTS OF BORE SEGMENTS AND ACCESSORIES, IN POUNDS.

Part.	No.	Material.	Weight, in pounds.
Bore Segment No. 1	1	Cast steel	3 004.0
Bore Segment No. 2	1	" "	2 628.0
Distance piece	1	" "	423.5
Key	1	" "	34.3
Plug	1	" "	1 192.5
Yoke	1	" "	57.3
Dogs	2	" "	106.0
Slot cover	1	Rolled steel	6.4
Plug cover	1	Cast iron	162.0
Dog holders	2	Rolled steel	6.4
Complete weight of one pair, without bolts			7 620.4

Sump Segments.—In order to provide sumps to collect the drainage and leakage water in the subaqueous tunnels, special "sump segments" were installed in each tunnel at the lowest point—about Station 241 + 00. The details of the design are shown in Fig. 14. The segment was built into the tunnel invert as though it were an ordinary *"A"* segment. In building the sump, three lining castings were bolted, one on top of the other, and attached to the flat upper surface of the sump segment; meanwhile, the bolts attaching the sump segment to the adjacent tunnel plates were taken out and the plate and lining segments were forced through the soft mud by hydraulic jacks, the three 6-in. holes in the bottom of the sump segment being opened in order to minimize the resistance. The sump when built appeared as shown in Fig. 14, the top connection being made with a special casting, as shown.

The capacity of each sump is 500 gal., which is about the quantity of water entering the whole length of each subaqueous tunnel in 24 hours.

Cross-Passages.—When the contract was let, provision was made for cross-passages between the tubular tunnels, in the form of special castings to be built into the tunnel lining at intervals. However, the idea was given up, and these castings were not made. Later, however, after tunnel building had started, the question was raised again, and it was thought that such cross-connections would be very useful to the maintenance forces, that it might be possible to build them safely, and that their subsequent construction would be made much easier if some provision were made for them while the shields were being driven. It was therefore arranged to build, at intervals of about 300 ft., two consecutive rings in each tunnel, at the same station in each tunnel, with their longitudinal flanges together, instead of breaking joint, as was usually done. The keys of these rings were displaced twelve bolt holes from their normal positions toward the other tunnel. This brought the keys about 6 ft. above the bench, so that if they were removed, together with the *B* plates below them, an opening of about 5 by 7 ft. would be left in a convenient position with regard to the bench.

Nothing more was done until after the tunnels were driven. It was then decided to limit the cross-passages between the tubular tunnels to the landward side of the bulkhead walls. They were ar-

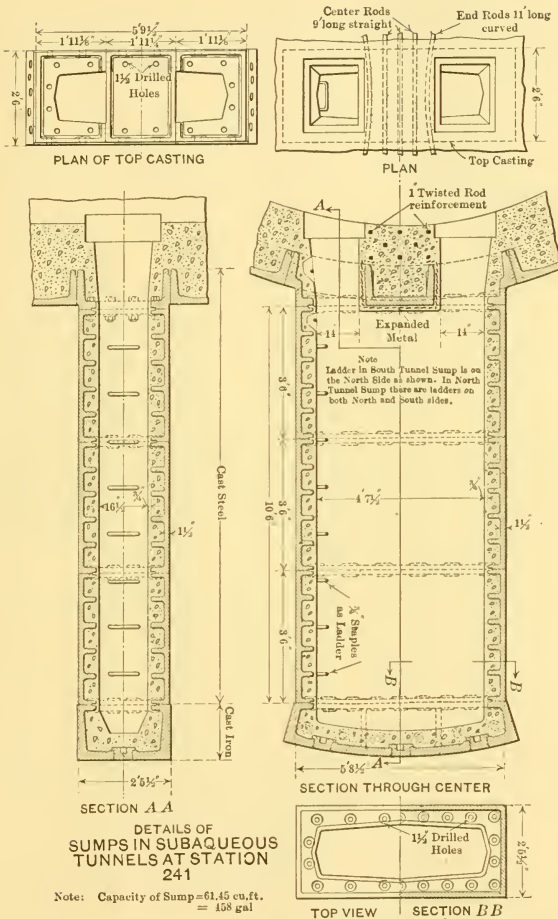

PLAN OF TOP CASTING
1½ Drilled Holes
Center Rods 9' long straight
End Rods 11' long curved
Top Casting
PLAN
1" Twisted Rod reinforcement
Expanded Metal
Note
Ladder in South Tunnel Sump is on the North Side as shown. In North Tunnel Sump there are ladders on both North and South sides.
Cast Steel
Cast Iron
¾" Staples as Ladder
SECTION A A
SECTION THROUGH CENTER
DETAILS OF SUMPS IN SUBAQUEOUS TUNNELS AT STATION 241
Note: Capacity of Sump = 61.45 cu. ft. = 458 gal
TOP VIEW (CONCRETE REMOVED)
SECTION B B

FIG. 14.

ranged as follows: three on the New York side, at Stations 203 + 22, 206 + 80, and 209 + 80, and two on the New Jersey side, at Stations 255 + 46 and 260 + 14. The cross-passages are square in cross-section.

TABLE 21.—Weights of Sump Segments.

Part.	Number.	Material.	Weight, in pounds.
Middle top casting	1	Cast steel	880
End top castings	2	" "	1 718
Lining castings	3	" "	18 232
Sump segment	1	Cast iron	3 560
Total weight per sump, exclusive of bolts			24 390

Turnbuckle Reinforcement for Cast-Iron Segments.—During the period of construction, a certain number of cast-iron segments, mostly in the roof, but in some cases at Manhattan in the invert, behind the river lines, became cracked owing to uneven pressures of the ground. Before the concrete lining was put in, considerable discussion occurred as to the wisest course to pursue with regard to these broken plates. It was finally thought best not to take the plates out, as more harm than good might be done, but to reinforce them with turnbuckles, as shown in Fig. 15. The number of broken segments was distributed as follows:

North Manhattan Tunnel... 87, chiefly in silt (not under the river),
South Manhattan Tunnel... 7, chiefly in silt (" " " "),
North Weehawken Tunnel... 24, chiefly in sand (" " " "),
South Weehawken Tunnel.. 48, chiefly in silt, under the Fowler Warehouse.

The chief features of the tunnel lining have now been described, and, before giving any account of the methods of work, it will be well to mention briefly the salient features of the concrete lining which is placed within the actual lining.

Design of Concrete Lining.

This concrete lining will be considered and described in the following order:

The New York Shield Chambers,
Standard Cross-Section of Concrete Lining of Shield-Driven Tunnels,

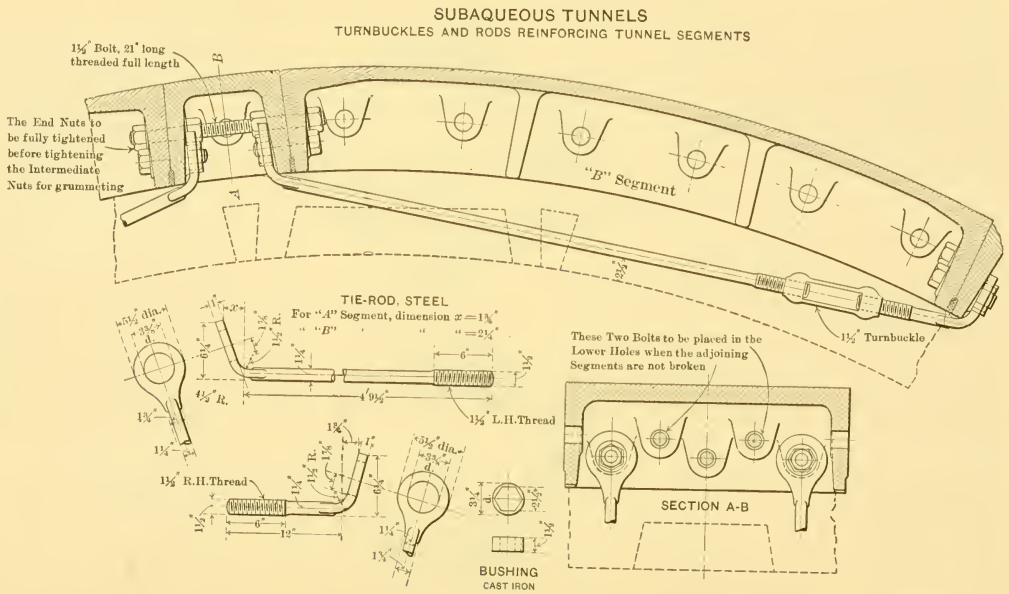
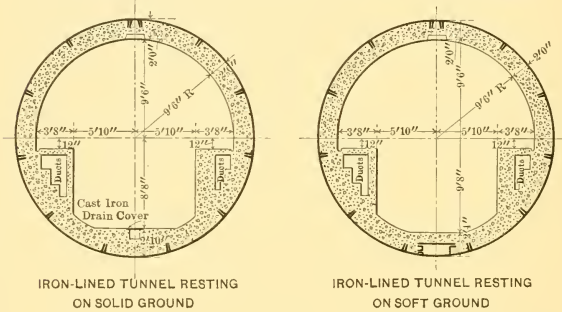

SUBAQUEOUS TUNNELS
TURNBUCKLES AND RODS REINFORCING TUNNEL SEGMENTS
1½" Bolt, 21" long threaded full length
The End Nuts to be fully tightened before tightening the Intermediate Nuts for grummeting
"B" Segment
1½" Turnbuckle
TIE-ROD, STEEL
For "A" Segment, dimension x = 1⅜"
" "B" " " = 2¼"
1½" L.H.Thread
1½" R.H.Thread
These Two Bolts to be placed in the Lower Holes when the adjoining Segments are not broken
SECTION A-B
BUSHING
CAST IRON

FIG. 15.

Final Lines and Grades, and How Obtained,
Steel Rod Reinforcement of Concrete,
Cross-Passage Lining,
Special Provision for Surveys and Observations.

The New York Shield Chambers.—The cross-section of the concrete lining of these chambers is shown by Plate XXXII, referred to in the Land Tunnel Section. They are of the twin-tunnel double-bench type. The deep space beneath the floor is used as a sump for drainage, and manholes for access to the cable conduits are placed in the benches.

TYPES OF CONCRETE LINING OF SHIELD-DRIVEN TUNNELS.



IRON-LINED TUNNEL RESTING ON SOLID GROUND

IRON-LINED TUNNEL RESTING ON SOFT GROUND

FIG. 16.

Standard Cross-Section of Concrete Lining of Shield-Driven Tunnels.—The cross-section of the concrete lining of the tube tunnel is shown in Fig. 16. There are two main types, one extending from the shield chambers to the first bore segment, that is, to where the tunnel leaves solid ground and passes into silt, and the other which extends the rest of the way. The first type has a drain in the invert, the second has not.

The height from the top of the rail to the soffit of the arch being less than 16 ft. 11 in., overhead pockets for the suspension of electrical conductors were set in the concrete arch on the vertical axis line at 10-ft. centers. These pockets are shown in Fig. 16. The benches are utilized for the cable conduits in the usual way. Ladders are provided on one side at 25-ft. and on the other side at 50-ft.

intervals, to give access from the track level to the top of the benches. Refuge niches for trackmen are placed at 25-ft. intervals on the single-way conduits side only, as there is not enough room in front of the 4-way ducts. Manholes for giving access to the cable conduits, both power, and telephone and telegraph, are at 400-ft. intervals.

Final Lines and Grades, and How Obtained.—It may be well to explain here how the final lines and grades for the track, and therefore for the concrete lining, were obtained and determined. It is first to be premised that the standard cross-section of the tunnel (that is, of the concrete and iron lining combined) is not maintained throughout the tunnel. In other words, the metal lining is of course uniform, or practically so, throughout; the interior surface of the concrete lining is also uniform from end to end, but the metal lining, owing to the difficulty of keeping the shields, and hence the tunnels built within them, exactly on the true line and grade, is not on such lines and grades; the concrete lining is built exactly on the pre-arranged lines and grades, consequently, the relative positions of the concrete and metal linings vary continually along the length of the structure, according to whether the metal lining is higher or lower than it should be, further to the north or to the south, or any combination of these.

As before stated, it was strongly desired to encroach as little as possible on the standard 2-ft. concrete arch, and after some discussion it was decided that a thickness of 1 ft. 6 in. was the thinnest it was advisable to allow. This made it possible to permit the metal lining of the tunnel to be 6 in. lower, in respect to the level of the track at any point, than the standard section shows, and also allowed the center line of the track to have an eccentricity of 6 in. either north or south of the center line of the tunnel. This only left to be settled the extent to which the metal lining might be higher in respect to the track than that shown on the standard section.

This amount was governed by the desirability of keeping sufficient clearance between the top of the rail and the iron lining in the invert to admit of the attachment of pile foundations and all the accompanying girder-track system which would necessarily be caused by the use of piles, should it ever become apparent after operation was begun, that, after all, it was essential to have the tunnels supported in this way. Careful studies were made of the clearance necessary,

and it was decided that 4 ft. 9 in. was the minimum allowable depth from the top of the rail to the outside of the iron at the bottom. This meant that the iron lining could be 3 in. higher, with respect to the track level, than that shown on the standard section.

All the determining factors for fixing the best possible lines and grades for the track within the completed metal lining were now at hand. In March, 1908, careful surveys of plan and elevation were made of the tunnels at intervals of 25 ft. throughout. The following operations were then performed to fix on the best lines and grades:

First, for Line: It has been explained that the permissible deviation of the center line of the track on either side of the center line of the tunnel was 6 in. Had the metal lining been invariably of the true diameter, it would have been necessary to survey only one side of the tunnel; this would have given a line parallel to the center line, and might have been plotted as such; then, by setting off 6 in. on either side of this line, there would have been obtained a pair of parallel lines within which the center line of the track must lie. Owing to variations in the diameter of the tunnel, however, such a method was not permissible, and therefore the following process was used:

When running the survey lines through the tunnel (which were the center lines used in driving the shields), offsets were taken to the inner edges of the flanges of the metal lining, both on the north and south sides, at axis level at each 25-ft. interval. On the plat on which the survey lines were laid down, and at each point surveyed, a distance was laid off to north and south equal to the following distances:

Offset, as measured in the tunnel to north (or south), minus 10.08 ft.

This 10.08 ft. (or 10 ft. 1 in.) represents 10 ft. 7 in., the true radius to inside of iron, minus 6 in., the permissible lateral deviation of the track from the axis of the tunnel.

The result of this process was two lines, one on either side of the survey lines, not parallel to it or to each other, but approaching each other when the horizontal diameter was less than the true diameter, receding from each other when the diameter was more, and exactly 12 in. apart when the diameter was correct. As long as the center line of the track lay entirely within these two limiting lines, the con-

dition that the concrete arch should not be 6 in. less in thickness than the standard 2 ft. was satisfied, and in order to arrive at the final line, the longest possible tangents that would be within these limits were adopted as the final lines; and, as the survey lines were those used in driving the tunnel shields (that is, the lines to which it was intended that the track should be built), the amount by which the new lines thus obtained deviated from the survey lines was a measure of the deviation of the finally adopted track and concrete line from the original contract lines.

Next, for Grades: The considerations for grade were very similar to those for line. If the vertical diameter of the tunnel had been true at each 25-ft. interval surveyed, it would have been correct to plot the elevations of the crown (or invert) as a longitudinal section of the tunnel, and to have set up over those points others 6 in. above (as the metal lining could have been 6 in. lower than the standard section, which is equivalent to the track being an equal amount higher), and below these crown or invert elevations others 3 in. lower (as the metal lining could be 3 in. higher).

Then, by joining the points 6 in. above in one line and those 3 in. below in another, there would have been obtained lines of limitation between which the track grades must lie. However, as the tunnel diameter was not uniformly correct, a modification of this method had to be made, as in the case of the line determination, the principle, however, remaining the same.

The elevations were taken on the inner edges of the circumferential flanges of the metal lining, not only in the bottom, but also in the top, of the tunnel, at each 25-ft. interval; then, for the upper limit of the track at each such interval the following was plotted:

Elevation of inner edge of flange at top, minus 16.58 ft.

This 16.58 ft. (or 16 ft. 7 in.) was obtained thus: The standard height from the top of the rail to the inner edge of the iron flange is 17 ft. 1 in., but, as the track may be 6 in. above the standard or normal, the minimum height permissible is 16 ft. 7 in. For the lower limit of track at each 25-ft. interval the following was plotted:

Elevation of inner edge of flange at bottom, plus 3.83 ft.

This 3.83 ft. (or 3 ft. 10 in.) was obtained thus: The standard height from the top of the rail to the inner edge of the iron flange is 4 ft. 1 in. (5 ft. to outside of iron, less 11 in. for depth of flange),

but, as the track may be 3 in. below the standard, the minimum height permissible is 4 ft. 1 in. less 3 in., or 3 ft. 10 in.

By plotting the elevations thus obtained, two lines were obtained which were not parallel but were closer together or further apart according as the actual vertical diameter was less or greater than the standard, and the track grade had to lie within these two lines in order to comply with the requirements indicated above. The results of these operations for the North Tunnel are shown on Plate XXXVI.

The greatest deviations between the lines and grades in the subaqueous tunnels as determined by these means and those as originally laid out in the contract drawings are on the Weehawken side, and were caused by the unexpected behavior of the tunnel when the shields were driven "blind" into the silt, causing a rise which could not be overcome, and the thrusting aside of one tunnel by the passage of the neighboring one. Had this unfortunate incident not occurred, it is clear that it would have been possible to adhere very closely indeed to the contract lines and grades, although the deviation is small, considering all things.

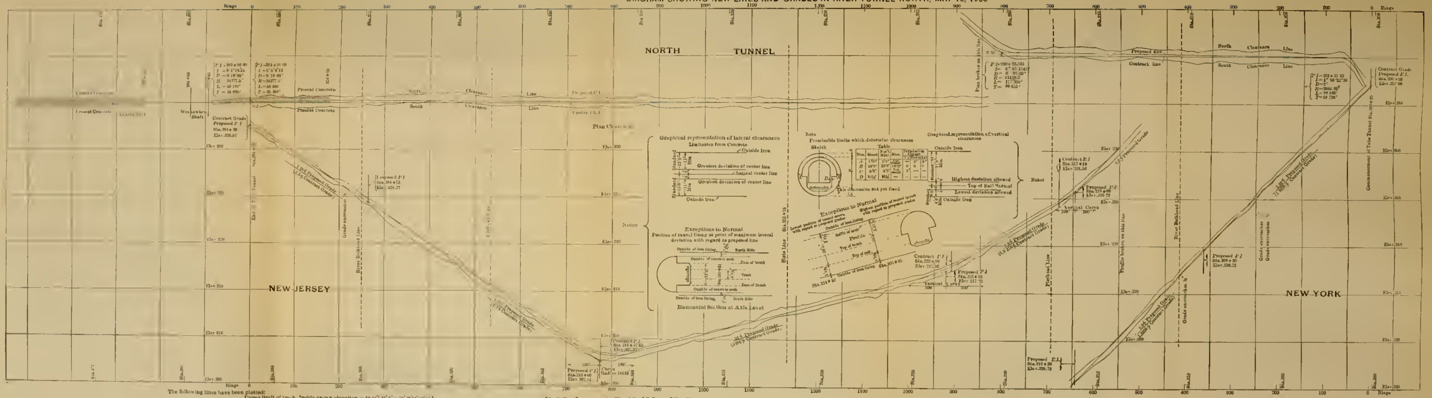
The internal outline of the concrete cross-section is uniform throughout, and is built on the lines and grades thus described.

Steel Rod Reinforcement of Concrete.—The original intention had been to line the metal lining of the tube tunnels with plain concrete, but, as the discussion on the foundation question continued, it was felt advisable, while still it was intended to put in the foundations, to guard against any stresses which were likely to come on the structure, by using a system of steel rods embedded circumferentially within the concrete. Designs were made on this basis, and even the necessary material prepared, before the decision to omit the piles altogether was reached. However, in order to provide a safeguard for the structure where it is partly or wholly beyond the solid rock, it was decided to use reinforcement, even with the piles omitted.

For this purpose the tunnel was considered as a girder, and longitudinal reinforcement was provided at the top and bottom. The top reinforcement extends from a point 25 ft. behind the point where the crown of the tunnel passes out of rock on the New York side to where the crown passes into rock on the New Jersey side. The bottom reinforcement extends from where the invert of the tunnel

PLATE XXXVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1155.
HEWETT AND BROWN ON
PENNSYLVANIA R. R. TUNNELS: NORTH RIVER TUNNELS.

DIAGRAM SHOWING NEW LINES AND GRADES IN RIVER TUNNEL NORTH, MAY 13, 1908



The following lines have been plotted:

On Profile: Upper limit of track Inside crown elevation − 18.56′ (16′ 7″ − 18′ (0′ 11″ + 6″)) / Lower limit of track Inside invert elevation + 3.85 (3′ 10″ − 3′ (0′ 11″ + 4″)) } shown thus / Proposed new grade, shown thus

On Plan Limitation from concrete N. and S. of C. L. = Offset N. or S. to side of tunnel − 10.06 (10′ 1″ − 11′ 6″ (0′ 11″ + 0′ 6″)) shown thus / Proposed new line shown thus

passes out of rock on the New York side to where it passes into rock on the New Jersey side.

The reinforcement both at top and bottom consists of twenty 1-in. square twisted rods, ten placed symmetrically on either side of the vertical axis, 9 in. apart from center to center and set 4 in. (to their centers) back from the face of the concrete.

As a further precaution, circumferentially-placed rods were used on the landward side of the river lines, mainly to assist in preventing the distortion of shape which might occur here, either under present conditions, such as under the Fowler Warehouse at Weehawken, or under any possible different future conditions, such as might be brought about by building some new structure in the vicinity of the tunnels.

For purposes of classification of the circumferential reinforcement, the tunnel was divided into two types, *"B"* and *"C";* (Type *"A"* covering the portion which, being wholly in solid rock, was not reinforced at all).

Type *"B"* covers the part of the tunnels on both sides of the river lying between the point where the top of the tunnel passes out of rock and the point where the invert passes out of rock on the Manhattan side, or out of gravel on the Weehawken side. The reinforcement consists of twenty 1-in. square longitudinal rods in the crown of the tunnel, as described for the general longitudinal reinforcement, together with 1-in. square circumferential rods at 10-in. centers, and extending over the arch to 2 ft. 3 in. below the horizontal axis.

Type *"C"* extends from the latter limit of Type *"B"* to the river line on each side, and consists of longitudinal reinforcement in both top and bottom, as described before, together with circumferential reinforcement entirely around the tunnel, and formed of 1-in. square twisted rods at 15-in. centers.

Type *"D"* consists of longitudinal reinforcement only, and extends from river line to river line, thus occupying 72.5% of the length in which concrete is used. The reinforcement consists of twenty 1-in. twisted rods at 9-in. centers in the crown, and twenty 1-in. rods at 9-in. centers in the invert. In addition to the three standard types, *"B," "C,"* and *"D,"* there were two sub-types which were used in Type *"D,"* and in conjunction with it wherever the thickness of the center of the concrete arch became less than 1 ft. 6 in., measuring to

the outside of the metal lining. This thickness was one of the limits used in laying out the lines and grades, and in general the arch was not less than this. There were one or two short lengths, however, where it was less, for, if the arch thickness requirement had been adhered to, it would have resulted in a break of line or grade for the sake of perhaps only a few feet of thin arch, and it was here that the sub-types came into play.

Sub-type 1 was used where the arch was less than 1 ft. 6 in. thick at the top. The extra reinforcement here consisted of 1-in. square twisted rods, 16 ft. long, laid circumferentially in the crown at 10-in. centers.

Sub-type 2 was used where the arch was less than 1 ft. 6 in. thick at the side. The extra reinforcement here consisted of 1-in. square twisted rods, 16 ft. long, laid circumferentially, at the side on which the concrete was thin, at 10-in. centers. Very little of either of these two sub-types was used. The entire scheme is shown graphically and clearly on Plate XXXVII.

Cross-Passage Lining.—There are two main types of cross-passages: Lined with steel plates, and unlined.

There is only one example of lining with steel plates, namely, the most western one at Weehawken. This is built in rock which carried so much water that, in order to keep the tunnels and the passage dry, it was decided to build a concrete-lined passage, without attempting to stop the flow of water, and within this to place a riveted steel lining, not in contact with the concrete, but with a space between the two. This space was drained and the water led back to the shield chamber and thence to the Weehawken Shaft sump. The interior of the steel lining is covered with concrete.

In the passages not lined with steel plates the square concrete lining is rendered on the inside with a water-proof plaster. Each of the passages is provided with a steel door.

Provisions in Concrete Lining for Surveys and Observations.—The long protracted discussion as to the provision for foundations in these tunnels led to many surveys, tests, and observations, which were carried out during the constructive period, and, as it was desired to continue as many of these observations as possible up to and after the time when traffic started, certain provisions were made in the

PLATE XXXVII.
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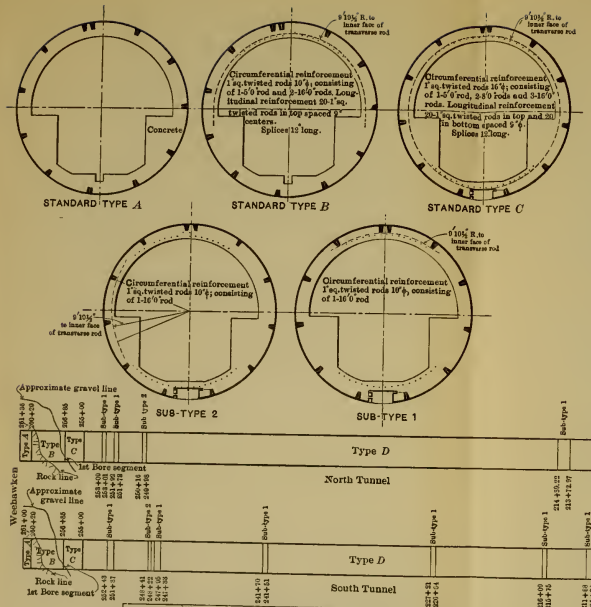
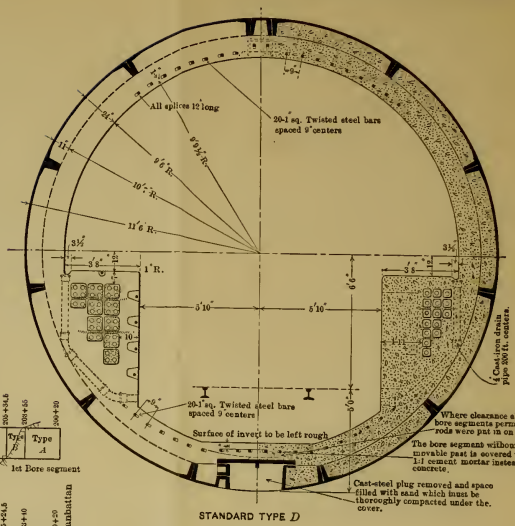
HEWETT AND BROWN ON
PENNSYLVANIA R. R. TUNNELS: NORTH RIVER TUNNELS





SUBAQUEOUS TUNNELS

CROSS-SECTIONS

SUB-TYPES OF REINFORCEMENT, COMBINED WITH STANDARD

Sub Type	Description of Location	Description of Lining	Total linear feet of tunnels	Wt. of steel per lin. ft. of tunnel	Total wt. of steel
1	Where concrete lining is less than 18" thick in the crown.	1" square twisted circumferential rods in crown 10" centers, 16'0" long.	435.25	66.048	28.745
2	Where concrete lining is less than 18" thick at side.	1" square twisted circumferential rods at side 10" centers, 16'0" long.	37	60.048	2.444

Note:

Above estimates of weights are based on a weight of 2.44 lb. per linear ft. of bar and an assumed average net length of longitudinal bar of 11'0."

STANDARD CONCRETE LINING

Type	Description of Location	Description of Lining	Total linear feet of tunnels	Wt. of steel per lin. ft. of tunnel	Total wt. of steel
A	In full rock.	Plain concrete	851		
B	From about 20" ft. within full rock to where rock disappears in bottom of tunnel in Manhattan and where gravel and sand disappear in bottom of tunnel in Weehawken.	20-1" sq. twisted longitudinal rods in top 9'0" 1" sq. twisted circumferential rods in arch 10" centers.	1034	228.42	236 181
C	From where rock disappears in Manhattan and gravel and sand in Weehawken to river lines.	20-1" sq. twisted longitudinal rods in top and 20" in bottom 9'0" 1 sq. twisted circumferential rods all around 10" centers.	1451	341.25	495 153
D	Between river lines.	20-1" sq. twisted longitudinal rods in top and 20" in bottom, 2" centers.	8800	151.36	1 341 050

concrete lining whereby these requirements might be fulfilled. The chief points on which information was desired were as follows:

The change in elevation of the tunnel,
The change in lateral position of the tunnel,
The change in shape of the tunnel,
The tidal oscillation of the tunnel.

A detailed account of these observations will be found in another paper on this work, but it may be said now that it was very desirable to be able to get this information independently of the traffic as far as possible, and therefore provision was made for carrying on the observations from the side benches.

For studying the changes in level of the tunnel, a permanent bench-mark is established in each tunnel where it is in the solid rock and therefore not subject to changes of elevation; throughout the tunnel, brass studs are set in the bench at intervals of about 300 ft. A series of levels is run every month from the stable bench-mark on each of these brass plugs, thus obtaining an indication of the change of elevation that the tunnels have undergone during the month.

These results are checked on permanent bench-marks in the subaqueous portion of the tunnels. These consist of rods, encased in pipes of larger diameter, which extend down through the tunnel invert into the bed-rock below the tunnel. Leakage is kept out by a stuffing-box in the invert. By measuring between a point on these rods where they pass through the invert and the tunnel itself a direct reading of the change of elevation of the tunnel is obtained. These measurements are taken at weekly intervals, and, as the tunnels are subject to tidal influences, being lower at high tide than at low tide, are always taken under the same conditions as to height of water in the river. These permanent bench-marks are at Stations 209 + 05 and 256 + 02 (about 100 ft. on the shoreward side of the river line in each case) in the South Tunnel, at Stations 220 + 00 and 243 + 86, also in the South Tunnel, and at Station 231 + 78 in the North Tunnel. In order to study the lateral change of position, a base line was established on the side bench at each end of each tunnel in the portion built through the solid rock.

At intervals of about 300 ft. throughout each tunnel, alignment pockets are formed in the concrete arch, also above the bench, on the

south bench of the North Tunnel and the north bench of the South Tunnel. In each pocket is placed a graduated and verniered brass bar, so that, when the base line is projected on these bars, the lateral movement of the tunnel can be read directly. As it was desirable to have as much cross-connection as possible between the tunnels at the points where the instruments were to be set up, five of the main survey stations were set opposite each of the five cross-passages. Then, for the purpose of increasing the cross-connection still further, pipes 6 in. in diameter were put through from one tunnel to the other at axis level at Stations 220 + 60, 231 + 78, 234 + 64, 241 + 99, and 251 + 13, and a survey station was put in opposite each one

Points were established at Station 220 + 00, which is the point of intersection for the curve on the original center line of the tunnel, and also at Station 220 + 23, where the intersection of the track center line comes in the North Tunnel. As it was desirable to have the survey stations not much more than 300 ft. apart, so as to obtain clear sights, other stations were established so that the distances between survey stations were at about that interval.

For studying changes of shape in the tunnel, brass "diameter markers" were inserted at each survey station in the concrete lining at the extremities of the vertical and horizontal axes. These were pieces of brass bar, $\frac{3}{8}$ in. in diameter and 6 in. long, set in the concrete and projecting $\frac{5}{8}$ in. into the tunnel, so that a tape could be easily held against the marker and read.

For obtaining the tidal oscillation of elevation of the tunnel, recording gauges are attached to the invert of the tunnel at each of the five permanent bench-marks referred to above in such a way that the recording pencil of the gauge is actuated by the rod of the permanent bench-mark. A roll of graduated paper is driven by clockwork below the recording pencil which thus marks automatically the relative movement between the moving tunnel and the stable rods. These have shown that in the subaqueous part of the tunnel there is a regular tidal fluctuation of elevation, the tunnel moving down as the tide rises, and rising again when the tide falls. For an average tide of about 5 ft. the tunnel oscillation would be about $\frac{1}{8}$ in. Before the concrete lining was placed, there was a tidal change in the shape of the tunnel, which flattened about $\frac{1}{64}$ in. at high tide. After the concrete lining was placed, this distortion seemed to cease.

The general design and plan of the work have been described, and before giving any account of the contractor's methods in carrying it out, Table 22, showing the chief quantities of work in the river tunnels, is presented.

Methods of Construction.

The following is an account of the methods used by the contractor in carrying out the plans which have already been described. First, it may be well to point out the sequence of events as they developed in this work. These events may be divided into six periods.

1.—Excavation and Iron Lining: June, 1903, to November, 1906;

2.—Caulking and grummeting the iron lining: November, 1906, to June, 1907;

3.—Surveys, tests and observations: April, 1907, to April, 1908;

4.—Building cross-passages and capping pile bores: April, 1908, to November, 1908;

5.—Placing the concrete lining: November, 1908, to June, 1909;

6.—Cleaning up and various small works: June, 1909, to November, 1909.

The tunnels were under an average air pressure of 25 lb. per sq. in. above normal for all except Periods 5 and 6, during which times there was no air pressure in the tunnels.

All the work will be described in this paper except that under Period 3 which will be found in another paper.

Period 1.—Excavation and Iron Lining, June, 1903, to November, 1906.—Table 23 gives the chief dates in connection with this period.

Manhattan Shield Chambers.—The Manhattan shield chamber construction will be first described. The Weehawken shield chambers have been described under the Land Tunnel Section, as they are of the regular masonry-lined Land Tunnels type, whereas the Manhattan chambers are of segmental iron lining with a concrete inner lining.

During the progress of excavation, the location of the New York shield chambers was moved back 133 ft., as previously described in the "Land Tunnel" Section, and when the location had been finally decided, there was a middle top heading driven all through the length now occupied by the shield chamber. Narrow cross-drifts were taken out at right angles to the top heading, and from the ends of these the wall-plate headings were taken out. Heavy timbering was used, as

TABLE 22.—Quantities of Work in Subaqueous Tunnels.

Description, Quantity, Length, etc.		Type. Manhattan shield chambers.	Cast iron, ordinary pocketless.	Cast iron, ordinary pocket.	Cast iron, heavy pocketless.	Cast steel, ordinary pocketless.	Total.
Length, in feet.		59.00	4 374.99	2 146.3	5 522.05	152.66	12 255.00 ft.
Excavation, in cubic yards.	Total	1 884	67 344	33 038	85 001	2 349	189 616 cu. yd.
	Per linear foot	31.9	15.4	15.4	15.4	15.4	
Cast-iron tunnel lining, in pounds.	Total	847 042	39 643 120	19 715 405	61 559 845	.....	121 765 412 lb.
	Per linear foot	14 357	9 061	9 186	11 148	.. ..	
Cast-steel tunnel lining, in pounds.	Total	.....	1 544 962	757 938	2 730 905	1 549 711	6 583 516 lb.
	Per linear foot	.....	353.1	353.1	494.5	10 151.4	
Steel bolts and washers, in pounds.	Total	23 627	1 475 991	724 095	2 935 455	51 266	5 210 434 lb.
	Per linear foot	400.46	337.37	337.00	531.59	335.82	
Rust joints, in linear feet.	Total	3 376	170 755	83 935	218 656	5 996	482 718 ft.
	Per linear foot	57.2	39.0	39.1	39.6	39.3	
Concrete, in cubic yards.	Total	766	20 030	9 827	25 282	713	56 618 cu. yd.
	Per linear foot	12.98	1.58	4.58	4.58	4.58	
Steel beams, plates, etc., in pounds.	Total	12 346	83 774	41 098	105 738	7 432	250 388 lb.
	Per linear foot	2 092.5	19.1	19.1	19.1	48.7	
Steel bolts, hooks, etc., in pounds.	Total	1 328	36 980	18 142	46 675	1 471	104 596 lb.
	Per linear foot	22.5	84.5	84.5	84.5	96.4	
Expanded metal, in pounds.	Total	594	2 215	1 086	2 795	62	6 752 lb.
	Per linear foot	10.07	0.506	0.506	0.506	0.406	
Vitrified conduits, in duct feet.	Total	2 560	235 903	115 728	297 752	7 757	659 700 duct ft.
	Per linear foot	43.49	53.92	53.92	53.92	50.81	

TABLE 23.—Excavation and Iron Lining.

		North Manhattan.	North Weehawken.	South Manhattan.	South Weehawken.
Shaft and preliminary headings	Begun	June 10, '03.	June 11, '03.	June 10, '03.	June 11, '03.
Shaft and preliminary headings	Finished.	December 11, '03.	September 1, '04.	December 11, '03.	September 1, '04.
Excavation of shield chamber	Begun	May 24, '04.	January 16, '05.	May 24, '04.	January 16, '05.
Excavation of shield chamber	Finished.	January 21, '05.	March 25, '05.	May 13, '05.	April 19, '05.
Cast-iron lining of shield chambers	Begun	February 4, '05.	None.	May 15, '05.	None.
Cast-iron lining of shield chambers	Finished.	March 13, '05.	None.	June 14, '05.	None.
Excavation of tunnels begun before installation of shield		October 17, '04.	January 13, '05.	January 5, '05.	January 25, '05.
Commenced building falsework for shield		March 6, '05.	March 23, '05.	June 19, '05.	April 17, '05.
Shield parts received at shaft		March 11, '05.	March 20, '05.	June 22, '05.	April 24, '05.
Erection of shield begun		March 13, '05.	March 27, '05.	June 22, '05.	April 24, '05.
Erection of shield (structural steel)	Finished.	March 27, '05.	April 12, '05.	June 8, '05.	May 3, '05.
Erection of shield (hydraulic fittings)	Finished.	May 11, '05.	May 25, '05.	August 27, '05.	June 13, '05.
First ring of permanent cast-iron lining put in		May 12, '05.	May 29, '05.	August 27, '05.	June 14, '05.
First air lock bulkhead wall	Begun	May 29, '05.	June 15, '05.	September 18, '05.	June 21, '05.
First air lock bulkhead wall	Finished.	June 7, '05.	June 23, '05.	September 23, '05.	July 3, '05.
Air pressure first put in tunnel		June 25, '05.	June 29, '05.	October 6, '05.	July 8, '05.
Rock disappeared from invert of tunnel		December 1, '05.	October 31, '05.	February 8, '06.	September 21, '05.
First pair of bore segments built in tunnel		December 9, '05.	January 12, '06.	February 16, '06.	December 12, '05.
Rip-rap of river bulkhead wall met		February 8, '06.	None.	April 11, '06.	None.
First pile met (in river bulkhead wall at Manhattan, and Fowler warehouse foundation at Weekawken)		February 18, '06.	January 3, '06.	April 18, '06.	December 4, '06.
Last pile met		March 2, '06.	February 5, '06.	May 1, '06.	January 9 '06.
First ring erected on river side of shore line		March 3, '06.	February 6, '06.	May 9, '06.	January 19, '06.
Removing hood of shield	Begun	March 27, '06.	February 6, '06.	May 9, '06.	January 19, '06.
Removing hood of shield	Finished.	April 1, '06.	February 8, '06.	May 12, '06.	January 24, '06.
Second air-lock bulkhead wall	Begun	May 12, '06.	March 19, '06.	July 13, '06.	March 11, '06.
Second air-lock bulkhead wall	Finished.	May 21, '06.	March 24, '06.	July 21, '06.	March 18, '06.
Tunnel holed through with meeting tunnel		September 12, 1906.		October 9, 1906.	
Last ring of permanent cast-iron lining built in		October 9, 1906.		November 18, 1906.	

the rock cover was only about 6 ft., and the whole span to be covered was 60 ft. The process adopted was to excavate and timber the north side first, place the iron lining, and then excavate the south side, using the iron of the north side as the supports for the north ends of the segmental timbering of the south. The only incident of note was that at 2:00 A. M., on October 20th, 1904, the rock at the west end of the south wall-plate heading was pierced. Water soon flooded the workings, and considerable disturbance was caused in the New York Central Railroad yard above. The cavity on the surface was soon filled in, but to stop the flow of mud and water was quite a troublesome job.

The excavation was begun on May 24th, 1904, and finished on May 15th, 1905. The segments were placed by an erector consisting of a timber boom supported by cross-timbers running on car wheels on longitudinal timbers at each side of the tunnel. Motion was transmitted to the boom by two sets of tackle, and the heavy (5 000-lb.) segments were easily handled. The erection of the lining was started on February 4th, 1905, and finished on June 14th, 1905.

While the shield chambers were being excavated, bottom headings were run along the lines of the river tunnels and continued until the lack of rock cover prevented their being driven further. These were afterward enlarged to the full section as far as possible. The typical working force in the shield chambers was as follows:

Ten-hour Shifts.

Drilling and Blasting.

1 Foreman	@	$3.50
6 Drillers	"	3.00
6 Drillers' helpers	"	2.00
1 Blacksmith	"	3.50
1 Blacksmith's helper	"	2.25
1 Powderman	"	2.00
1 Waterboy	"	2.00
1 Nipper	"	2.00
1 Machinist	"	3.00
1 Machinist's helper	"	1.80

Mucking.

1 or 2 Foremen	@	$3.00
16 Muckers	"	2.00

A 24. N. R. D. Section Gy West South Tube Tunnel Manhattan, 23 feet external diameter. View of back of Shield 130 feet from Shield Chamber on its way Westwards to the North River. Oct. 9, 1906.

Fig. 1.

A 17 N.R.D. North Tube Tunnel Manhattan, Rear view of Shield during erection of first ring of iron lining in North River Tunnels. May 12, 1906.

Fig. 2.

Erection of Shields.—The tunneling shields have been described in some detail in the section of this paper dealing with the contractor's plant. They consist essentially of two parts, the structural steelwork and the hydraulic fittings. The former was made by the Riter Conley Manufacturing Company, of Pittsburg, Pa., and put up by the Terry and Tench Company, of New York City; the hydraulic fittings were made and put in by the Watson-Stillman Company, of New York City.

On the New York side, the shields were built inside the iron lining of the shield chambers, hence no falsework was needed, as the necessary hoisting tackle could be slung from the iron lining; at Weehawken, however, the erection was done in the bare rock excavation, so that timber falsework had to be used. The assembly and riveting took about 2 weeks for each shield; the riveting was done with pneumatic riveters, using compressed air direct from the tunnel supply.

After the structural steel had been finished, the shields, which had hitherto been set on the floor of the chambers in order to give room for working over the top, were jacked up to grade; this involved lifting a weight of 113 tons. While the hydraulic fittings were being put in, the shields were moved forward on a cradle, built of concrete with steel rails embedded, on which the shield was driven for the length in which the tunnel was in solid rock.

The installation of the hydraulic fittings took from 4 to 6 weeks per shield. The total weight of each finished shield was about 193 tons. The completed shield, as it appeared in the tunnel, is shown by Fig. 1, Plate XXXVIII. The typical force working on shield erection was as follows:

Ten-hour Shifts.

Shield Erection. (*Terry and Tench.*)

1	Superintendent	@	$13.00 per day
4	Foremen	"	5.50 " "
1	Timekeeper	"	2.50 " "
2	Engineers	"	4.50 " "
34	Iron workers	"	4.50 " "
7	Laborers	"	2.25 " "

Hydraulic Work. (*Watson-Stillman Company.*)

4	Mechanics	@	$4.00 per day

General Labor. (*O'Rourke Engineering Construction Company.*)

1 Inspector	@	$4.00	per	day
1 Foreman	"	4.00	"	"
8 Laborers	"	2.00	"	"
1 Engineer	"	2.50	"	"

After the shield was finished and in position, the first two rings of the lining were erected in the tail of the shield. These first rings were then firmly braced to the rock and the chamber lining; then the shield was shoved ahead by its own jacks, another ring was built, and so on.

The description of the actual methods of work in the shield-driven tunnels can now be given; this will be divided generally into the different kinds of conditions met at the working face, for example, Full Face of Rock, Mixed Face, Full Face of Sand and Gravel, Under River Bulkhead, and Full Face of Silt.

The last heading is the one under which by far the longest length of tunnel was driven, and, as not much has hitherto appeared descriptive of the handling of a shield through this material, considerable space will be devoted to it.

Full Face of Rock.—As was described when dealing with the shield chambers, as much as possible of the rock excavation was done before the shields were installed. On the New York side, about 146 ft. of tunnel was completely excavated, with 71 ft. of bottom headings beyond that, and at Weehawken, 58 and 40 ft. of tunnel and heading beyond, respectively. This was chiefly done to avoid handling the rock through the narrow shield doors. Test holes were driven ahead at short intervals to make sure that the rock cover was not being lost, but, nevertheless, at Weehawken, on February 14th, 1905, a blast broke through the rock and let the mud flow in, filling the tunnel for half its height for a distance of 300 ft. from its face.

Throughout the rock section the shield traveled on a cradle of concrete in which were embedded either two or three steel rails. In the portion in which the whole of the excavation had been taken out, it was only necessary to trim off projecting corners of rock. In the portion in which only a bottom heading had been driven, the excavation was completed just in front of the shield, the drilling below axis level being done from the heading itself, and above that

from the front sliding platforms of the shield. The holes were placed near together and drilled short, and very light charges of powder were used, so as to lessen the chance of knocking the shield about too much. In this work the small shield doors hampered the work greatly, and it might have been well to have provided a larger bottom opening which could have been subdivided or partly closed when soft ground was met; on the other hand, the quantity thus handled was small, owing to the fact that the greater part of the rock was excavated before the shields were installed.

The space outside the lining was grouted with a 1:1 mixture of Portland cement and sand. Large voids were hand-packed with stone before grouting. The details of grouting will be described later.

A typical working gang is given herewith. Two such gangs were worked per shield per 24 hours, 10 hours per shift. All this work was done under normal air pressure.

General:

½ Tunnel superintendent	@	$200.00	per month
1 Assistant tunnel superintendent	"	5.00	per day
1 General foreman	"	5.00	" "
½ Electrician	"	3.50	" "
½ Electrician's helper	"	3.00	" "
½ Pipefitter	"	3.00	" "
½ Pipefitter's helper	"	2.75	" "

Drilling:

1 Foreman	"	5.00	" "
3 Drillers	"	4.00	" "
3 Drillers' helpers	"	3.00	" "
1 Nipper	"	2.50	" "
½ Waterboy	"	2.50	" "
½ Powderboy	"	2.75	" "

Mucking:

1 Foreman	"	3.50	" "
8 Muckers	"	2.75	" "

Erecting Iron and Driving Shield:

1 Erector runner	"	4.00	" "
3 Iron workers	"	3.00	" "

The duties of such a gang were as follows: The tunnel superintendent looked after both shifts of one shield. The assistant or "walking boss" had charge of all work in the tunnel on one shift. The general foreman had charge of the labor at the face. The electricians looked after repairs, extensions of the cables, and lamp renewals. The pipefitters worked in both tunnels repairing leaks in pipes between the power-house and the working faces, extending the pipe lines, and attending to shield repairs, and in the latter work the erector runner helped.

The drillers stuck to their own jobs, which were not subject to interruption as long as the bottom headings lasted. One waterboy and one powderboy served two tunnels. The muckers helped the iron men put up the rings of lining, as well as doing their own work. The iron men tightened bolts, whenever not actually building up iron. The list does not include the transportation gang, which will be described under its own heading.

The rate of progress attained was 4.2 ft. per day per shield where most of the excavation had been done before, and 2.1 ft. where none had been done before.

When the shields had got far enough away from the shield chamber, and before rock cover was lost, the first air-lock bulkhead walls were put in.

Air-Lock Bulkhead Walls.—The specifications required these walls and all their fittings to be strong enough to stand a pressure of 50 lb. per sq. in. Accordingly, all the walls were of concrete, 10 ft. in thickness, except the first two, which were 8 ft. in thickness, and grouted up tight.

There were three locks in each bulkhead wall capable of holding men, namely, the top or emergency lock which is set high in order to afford a safe means of getting away in case of a flood; this lock was used continuously for producing the lines and levels into the tunnels. It was very small and cramped for this purpose, and a larger one would have been better, both for lines and emergencies. This lock was directly connected with the overhead platform (also called for in the specifications) which ran the whole length of the tunnels. Side by side, on the level of the lower or working platform of the tunnel, were the man lock and the muck lock. In addition a number of pipes were built in to give access to the cables and for passing pipes, rails, etc., in and out.

After each tunnel was about 1 200 ft. ahead of the first walls, a second wall was built just like the first, and no others were put in, so that altogether there were eight walls. This second wall not only gave an added safeguard to the tunnel but enabled the air pressure at the working face to be divided between the two walls, and this compression or decompression in stages, separated by a spell of walking exercise, was found to be very good for the health of those working in the air.

Mixed Face.—When the rock cover became so thin that it was risky to go on without the air pressure, the air pressure was turned on, starting with from 12 to 18 lb., which was enough to stop the water from the gravel on top of the rock. At first, when the surface of the rock was penetrated, the soft face was held up by horizontal boards braced from the shield until the shield was shoved. The braces were then taken out and, as soon as the shield had been shoved, were replaced by others. As the amount of soft ground in the face increased, the system of timbering was gradually changed to one of 2-in. poling boards resting on top of the shield and supported at the face by vertical breast boards, in turn held by 6 by 6-in. walings braced both through the upper doors to the iron lining and from the sliding platforms of the shield. The latter were in their forward position before the shield was shoved, the pressure being turned off and the exhaust valves opened just before the shove began. As the shield went ahead, the platform jacks gradually exhausted and thus held enough pressure on the face to keep it up. Fig. 17 is a sketch of this method. In driving through mixed ground a typical working gang was about as follows:

General:

⅓ Tunnel superintendent	@	$300.00	per month
1 Assistant tunnel superintendent	"	5.00	per day
1 General foreman	"	5.00	" "
½ Electrician	"	3.50	" "
½ Electrician's helper	"	3.00	" "
½ Pipefitter	"	3.25	" "
½ Pipefitter's helper	"	3.00	" "

Drilling:

1 Foreman	"	5.00	" "
2 Drillers	"	3.25	" "
2 Drillers' helpers	"	3.00	" "

Timbering:

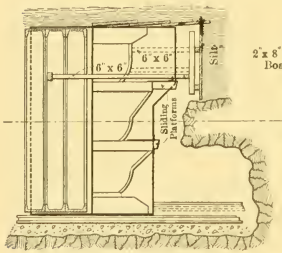
2 Timbermen	@	$2.50	per day
2 Timbermen's helpers	"	2.00	" "
Mucking:			
1 Foreman	"	3.50	" "
6 Muckers	"	2.75	" "
Erecting Iron and Driving Shield:			
1 Erector runner	"	3.25	" "
3 Iron workers	"	3.00	" "

The average rate of progress was 2.6 ft. per day.

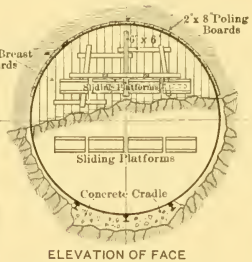
In this case there were three such gangs, each on an 8-hour shift.

Full Face of Sand and Gravel.—This condition of affairs was only met at Weehawken. Two systems of timbering were used. In the first system, Fig. 17, the ground was excavated 2 ft. 6 in. ahead of the cutting edge, the roof being held by longitudinal poling boards, resting on the outside of the skin at their back end and on vertical breast boards at the forward end. When the upper part of the face was dry, it was held by vertical breast boards braced from the sliding platform and through the shield doors to cross-timbers in the tunnel; the lower part, which was always wet, was held by horizontal breast boards braced through the lower shield pockets to cross-timbers in the tunnel. This system worked all right as long as the ground in the top was sandy enough and had sufficient cohesion to allow the polings to be put in, but, when the upper part was in gravel, thus making it impossible to put in the longitudinal polings or the vertical breasting, the second system came in. Here the excavation was only carried 1 ft. 3 in. (half a shove) ahead of the cutting edge, and the longitudinal polings were replaced by transverse boards supported by pipes which were placed in the holes provided in the shield to accommodate some telescopic poling struts which had been designed but not made. These pipes acted as cantilevers, and were in two parts, a 2½-in. pipe wedged tight into the holes and smaller pipes sliding inside them. After a small section of the ground had been excavated, a board was placed against it, one of the pipes was drawn out under it, and wedges were driven between it and the board. These polings were kept below the level of the hood, so that when the shield was shoved they would come inside of it; in addition, they were braced with vertical posts from the sliding platforms. The upper part of the face was held by longi-

METHOD OF TIMBERING FACE IN MIXED GROUND

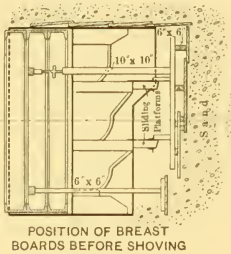


POSITION OF BREAST BOARDS BEFORE SHOVING

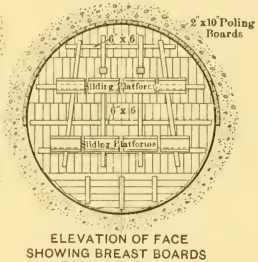


ELEVATION OF FACE SHOWING BREAST BOARDS FOR NEXT SHOVE

METHOD OF TIMBERING FACE IN SAND

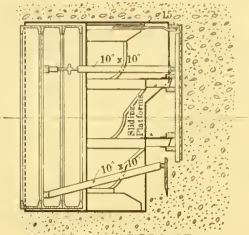


POSITION OF BREAST BOARDS BEFORE SHOVING

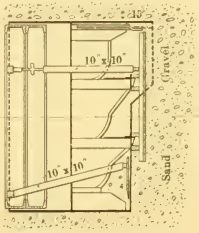


ELEVATION OF FACE SHOWING BREAST BOARDS FOR NEXT SHOVE

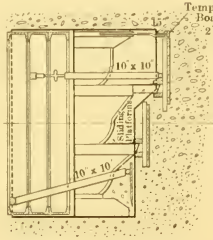
METHOD OF TIMBERING FACE IN SAND AND GRAVEL



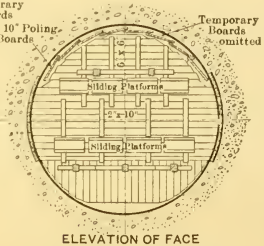
POSITION OF BREAST BOARDS BEFORE SHOVING



POSITION OF BREAST BOARDS AFTER SHOVING



SETTING FORWARD BREAST BOARDS FOR NEXT SHOVE



ELEVATION OF FACE SHOWING BREAST BOARDS FOR NEXT SHOVE

FIG. 17.

tudinal breast boards braced from the sliding platform by vertical "soldier" pieces. The lower part of the face was supported by vertical sheet-piling braced to the tunnel through the lower doors. Sometimes two rows of piling were used, but generally one, as shown in Fig. 17. Notwithstanding the fact that the breasting was only 1 ft. 3 in. ahead of the hood, the shield was moved its full stroke of 2 ft. 6 in., the ground around the cutting edge of the hood being scraped away by men working bars in the place from which the temporary breast boards at the circumference had been removed. The back pressure on the sliding platform jacks, when the exhaust valves were only partly open, offered a good deal of resistance, and held the face as long as the movement of the shield was continuous.

On one occasion, when for some reason the shield was stopped with the shove only partly done, and the exhaust valves had not been shut off, the platforms continued to slide and allowed the face to collapse; the shield platforms and doorways, however, caught the falling sand and gravel and the flow choked itself.

As soon as the rock surface was penetrated and the sand and gravel were met, which happened almost at the same time in the two Weehawken Tunnels, the escape of air increased enormously, and it at once became clear that it was impossible to keep enough air in the two tunnels by the methods then in use, even when working the three compressors, each capable of compressing 4 400 cu. ft. of free air per min. at top speed. When the shields just entered the sand and gravel, the face had been held by light breasting, without any special effort to prevent the escape of air, but when it was found impossible to supply enough air, a large amount of straw and clay was used in front of the boards.

This cut down the escape, but, as much air was escaping through the joints of the iron lining, these were plastered with Portland cement. Even then, the loss was too great, therefore one tunnel was shut down entirely and all the air was sent to the other. This allowed a pressure of 10 lb. to be kept up in the working tunnel, and this, though less than the head, was enough to allow progress to be made. In order to use one tunnel as a drain for the other, the two faces were always kept within 150 ft. of each other by working them alternately. The timbered face was never grouted, though this would have reduced the loss of air, as at the same time it would have decreased the progress very much, and any one who saw the racing engines in the power-

house, and realized that a breakdown of one of them would mean the loss of the faces, was ready to admit that the quicker this particular period was cut short, the better.

Above the sand and gravel lay the silt, and, when it showed in the roof, the escape of air was immediately reduced and the two faces could be worked simultaneously. Almost at the same time the piles supporting the large warehouse, known as the Fowler Building, were met. Although the face now took much less timber, the same system of breast boards as had been used in the gravel was kept up, but in skeleton form. They were set 2 ft. 6 in. ahead of the shield, however, instead of 1 ft. 3 in., and the transverse roof poling boards were replaced by longitudinals resting on the shield. The more piles in the face the less timbering was done. The piles were cut into handy lengths with axes and chisels.

All timbering was light compared with the weight of the ground, but, as the shove took place as soon as the set was made, it served its purpose. When a face was closed down the whole system was greatly reinforced by braces from the shield, the face of which was closed by the doors.

In driving through such a face the typical 8-hour shift gang was about as follows:

General:

⅓ Tunnel superintendent	@	$300.00	per month.
1 Assistant tunnel superintendent	"	5.00	per day.
1 General foreman	"	5.00	" "
½ Pipefitter	"	3.25	" "
½ Pipefitter's helper	"	2.75	" "
½ Electrician	"	3.00	" "
½ Electrician's helper	"	2.75	" "

Timbering:

3 Timbermen	"	2.50	" "
3 Timbermen's helpers	"	2.00	" "

Mucking:

1 Foreman	"	3.50	" "
6 Muckers	"	2.75	" "

Erecting Iron and Driving Shield:

1 Erector runner	"	3.25	" "
1 Foreman	"	4.00	" "
4 Iron workers	"	3.00	" "

The drillers were not kept on after the rock disappeared; a foreman was added who divided his time between iron erection and mucking.

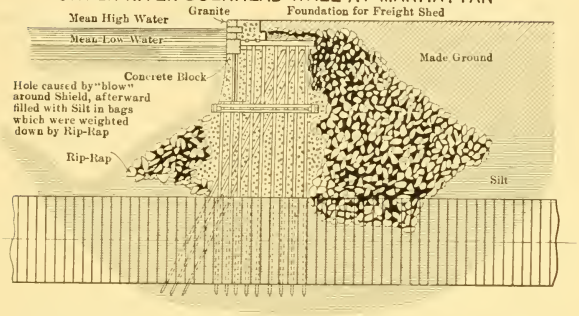
The average rate of progress in sand and gravel without piles was 5.1 ft. per day per shield. When piles and silt were met in the upper part of the face, the speed increased to 7.0 ft. per day.

Passing Under River Bulkhead.—At Weehawken no trouble was found in passing under the river wall, as the bulkhead consisted of only cribwork supported on silt, and, though the piles obstructed the motion of the shield, they were easily cut out, and the cribwork itself was well above the top of the shield.

On the New York side, however, conditions were not nearly as good. The heavy masonry bulkhead was supported on piles and rip-rap, as shown in Fig. 18. The line of the top of the shield was about 6 ft. above the bottom of the rip-rap, the spaces between the stones of which were quite open and allowed a free flow of water directly from the river. As soon, therefore, as the cutting edge of the shield entered the rip-rap there was a blow, the air escaping freely to the ground surface behind the bulkhead and to the river in front of it. Clay puddle, or mud made from the excavated silt, was used in large quantities to plug up the interstices between the stone in the working face, the air pressure being slightly greater than that needed to keep out the water holding it in place. The excavation of the rip-rap was a tedious affair, for it had to be removed one stone at a time and the spaces between the newly exposed stones plugged with mud immediately. One man stood ready with the mud while another loosened the stones with a bar. When the shield had advanced its own length in the rip-rap, another point for the escape of the air was exposed at the rear end of the shield. This loss was closed at the leading end of the last ring with mud and cement sacks.

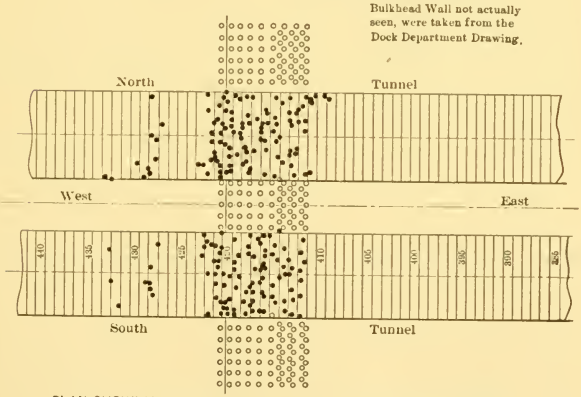
As long as the shield was stationary it was possible, by using these methods and exercising great care and watchfulness, to prevent excessive loss of air; but, while the shield was being shoved ahead, the difficulties were much increased, for the movement of the shield displaced the bags and mud as fast as they were placed, and it was only by shoving slowly and having a large number of men looking out for leaks and stopping them up the instant they developed that excessive loss of air could be prevented. In erecting the iron lining, as each segment was brought into position, it was necessary to clean off the

SKETCH SHOWING RIVER TUNNELS PASSING UNDER RIVER BULKHEAD WALL AT MANHATTAN



CROSS-SECTION OF RIVER BULKHEAD WALL ON AXIS OF NORTH TUNNEL

Note: The details of the River Bulkhead Wall not actually seen, were taken from the Dock Department Drawing.



PLAN SHOWING PILES REMOVED TO ALLOW PASSAGE OF SHIELD

FIG. 18.

leading surface of the previous ring and the adjacent portion of the tail of the shield; this was always accompanied by a slight "blow," and for some time the air pressure in the tunnel dropped from 25 to 20 lb., that is, from greater than the balancing pressure to less, every time a segment was placed, and on two occasions the "blow" became so great that the tunnel pressure was reduced considerably further, and in consequence the water from the river rushed in and was not stopped until it had risen about 4 ft. in the tunnel invert. On such occasions the surface of the river was greatly disturbed, rising more than 20 ft. in the air in a sort of geyser. A large quantity of grout (about 2 500 bbl. of cement and a similar quantity of sand in the North Tunnel and 1 000 bbl. in the South Tunnel) was used at this point; it was forced through the tunnel lining immediately behind the shield, greatly reducing the loss of air and helping to bind the rip-rap together.

When the shield had traveled 25 ft. through the rip-rap, the piles which support the bulkhead were met. One hundred of these which were spaced at 3-ft. centers in each direction, were cut out of the path of each shield in a distance of 35 ft. The presence of the piles caused considerable extra labor, as each pile had to be cut into several pieces with axes to enable it to be removed through the shield doors, otherwise they presented no difficulties. It was not necessary to timber the face, as the piles supported it most effectively.

When the river line had been passed, the "blow" still continued, and as there was no heavy ground above the tunnel the light silt was carried away into the water by the escaping air. At one time the cover over the crown of the tunnel was reduced to such an extent that for a distance of 30 ft. there was less than 10 ft. of very soft silt, and in some places none at all. Therefore, the shield was stopped and the air pressure reduced until it was less than the balancing pressure; the blow then ceased, and about 28 000 cement bags filled with mud were dumped into the hole (the location made it impossible to dump them *en masse* from a scow). They were then weighted down with rip-rap. This sealed the blow, and the work was continued without any further disturbance from this source. Just before the blow reached its maximum it was found that two of the piles which had been encountered were directly in the path of one of the proposed screw-piles. It was therefore decided to pull these,

and this was done with two 40-ton hydraulic jacks supported by the upper sliding platforms and acting on a horizontal timber which was connected to the piles by tie-rods and chains. The working force here was similar to that employed in the sand and gravel section previously described.

In Full Face of Silt.—A full face of silt was first met under the New York Central Railroad freight yard on the New York side. Up to this point the ground passed through had been either solid rock or a mixed face of rock and gravel. In both of these the full excavation had to be taken out before the shield could be shoved, and the soft ground had needed timbering. When the rock, gravel, and hardpan gave place to a full face of silt, the timber was removed, all the shield doors were opened, and the shield was shoved into the ground without any excavation being done by hand ahead of the diaphragm. As the shield advanced, the silt was forced through the open doors into the tunnel. After the work had gone on in this way for some time, taking in about 90% of the full volume of the tunnel excavation per foot forward, the air pressure was raised from 20 to 22 lb. The result was that the silt in the face got harder and flowed less readily through the shield, and the amount taken in fell to about 65% of the full volume. This manner of shoving at once caused a disturbance on the surface and the railroad tracks above the tunnel were raised, so that the pressure was lowered to 16 lb., then the muck got softer and the full volume of excavation was taken in; after a while the pressure was again raised to 20 lb.

The forcing of the shield through the silt resulted in a rising of the bed of the river, the amount that the bed was raised depending on the quantity of material brought into the shield.

If the whole volume of excavation was being brought in, the surface of the bed was not affected; when about 50% was being taken in, the surface was raised about 3 ft.; if the shield was being driven blind, the bed was raised about 7 ft.

The number of open doors was regulated so as to take in the minimum quantity of muck consistent with causing no surface disturbance. On the average, in the North Manhattan Tunnel, all the doors were open, but in the South Tunnel there were generally only five or six out of the total nine.

In front of the bulkhead wall at Manhattan the tunnels were under

Pier No. 72. This structure was supported on wooden piles, some 80 ft. or more in length, which came down below the tunnel invert. The piles which lay directly in the path of the tunnels, with a few exceptions, had been pulled. In driving the tunnels through this section, great care had to be taken not to disturb the piles on either side of the tunnels, as they supported a heavy trestle used in disposing of the excavation from the open cut in the terminal yard. To avoid such disturbance, a large portion of the total excavation had to be taken through the shields.

The first shield which passed the river bulkhead was the south one at Weehawken. As soon as this line was crossed the silt was found to be much softer than behind the wall, in fact it was like a fluid in many of its properties. The fluidity could be changed by varying the tunnel air pressure; for example, when the air pressure was made equal to the weight of the overlying material (water and silt), the silt was quite stiff, and resembled a rather soft clay; but when the air pressure was from 10 to 15 lb. per sq. in. lower, it became so liquid that it would flow through a 1½-in. grout hole in the lining, in a thick stream, at the rate of from 10 to 50 gal. per min. as soon as the plug was taken out. This was the point to which the contractor had long looked forward, as he expected to be able to close all his shield doors and drive the rest of the way across without taking in a shovelful of muck, as had just been done under the Hudson River, on the South Tunnel of the Hudson and Manhattan Railroad Company's Tunnels between Morton Street, New York City, and Hoboken, N. J. The doors were shut and the shield was shoved; the tunnel at once began to rise rapidly, notwithstanding that the heaviest possible downward leads that the clearance between the iron and the shield would allow were put on. At the same time, the pressures induced in the silt by the shield shouldering the ground aside caused the iron lining to rise about 2 in. as soon as the shield left it, and also distorted it, the horizontal diameter decreasing and the vertical diameter increasing by about as much as 1¼ in. An anxious discussion followed these phenomena, as the effects had been so utterly unexpected, and a good many different theories were advanced as to the probable cause. It was thought that the hood of the shield might have something to do with the trouble. The shield was stopped, the hood removed, the doors were shut, and the driving continued.

The same trouble was found, and it was impossible to keep to grade. Work was stopped, and the question was thoroughly debated; finally, on January 31st, 1906, the chief engineer directed that one of the shield doors be opened as an experiment and 50% of the excavation taken in.

The effect was instantaneous, the shield began to come down to grade at once, and it soon became necessary to close the door partially and reduce the quantity of muck taken in in order to prevent the tunnel from getting below grade. The other troubles from distortion, etc., ceased at the same time.

It was soon found that a powerful aid in the guidance of the shield was thus brought to hand, for, if high, the shield could be brought down by increasing the quantity of muck taken in, if low, by decreasing it. From this time forward, the quantity of muck taken in at each shove was carefully regulated according to the position of the tunnel with regard to grade and the nature of the ground. The quantity varied from nothing to the full volume displaced by the tunnel, and averaged 33% of the latter.

To regulate the flow, the bottom middle door was fitted with two steel angles behind which were placed 6 by 6-in. timbers. In this way the opening could be entirely closed or one of any size left. The muck flowed into the tunnel in a thick stream, as shown in Fig. 2, Plate XXXV, and, by regulating the rate of shove it could be made to flow just as fast as it could be loaded into cars.

In driving through the silt, the typical gang per shift of 8 hours per shield was as follows:

General:

⅓ Tunnel superintendent	@	$300	per month
1 Assistant tunnel superintendent	"	6.00	per day
1 General foreman	"	5.00	" "
½ Electrician	"	3.50	" "
½ Electrician's helper	"	3.00	" "
1 Foreman	"	4.00	" "
2 Pipefitters	"	3.50	" "
2 Pipefitters' helpers	"	3.25	" "

Mucking:

1 Foreman	"	4.00	" "
6 Muckers	"	3.00	" "

Erecting Iron and Driving Shield:

1 Foreman	@	$4.00	per day
1 Erector runner	"	3.50	" "
4 Iron workers	"	3.00	" "
3 Laborers	"	3.00	" "

Three such shifts were worked per day, and the air pressure averaged 25 lb. per sq. in.

The increase in the number of pipefitters was due to the greatly increased speed, and also the steadily increasing length of completed tunnel. The three laborers in the erection gang spent their whole time tightening bolts. The rate of progress in the silt under the river per ring of 2½ ft. was 3 hours 21 min., exclusive of all time when work was actually suspended. For a considerable part of the time only two 8-hour shifts were worked, owing to a shortage of iron caused by the change in the design of the lining, whereby the original lining was changed to a heavier one, and, as the work was also stopped for experiments and observations, the average of the actual total time, including all the time during which work was suspended, was 5 hours 32 min. per ring, or 10.8 ft. per day.

The junction of the shields under the river was made as follows: When the two shields of one tunnel, which had been driven from opposite sides of the river approached within 10 ft. of each other, the shields were stopped, a 10-in. pipe was driven between them, and a final check of lines and levels was made through the pipe. Incidentally, also, the first through traffic was established by passing a box of cigars through the pipe from the Manhattan shield to that from Weehawken. One shield was then started up with all doors closed while the doors on the stationary shield were opened so that the muck driven ahead by the moving shield was taken in through the other one's doors. This was continued until the cutting edges came together. All doors in both shields were then opened and the shield mucked out. The cutting edges were taken off, and the shields moved together again, edge of skin to edge of skin. The removal of the cutting edge necessitated the raising of the pressure to 37 lb. As the sections of the cutting edges were taken off, the space between the skin edges was poled with 3-in. stuff. Fig. 1, Plate XXXIX, is a view of the shields of the North Tunnel after being brought together and after parts of the interior frames had been removed. When

A 46. P. R. R. Tunnels, N. R. Div. Section G, River Tunnel North. View of Shields during dismantling after having met. Showing front edges of skins in contact.
Oct. 19, 06.

FIG. 1.

A 40. P. R. R. Tunnels, N. R. Div. Sect. G. River Tunnel, (South) Weehawken, lowering segment into invert of tunnel.
Aug. 29, 06.

FIG. 2.

everything except the skins had been removed, iron lining was built up inside the skins, the gap at the junction was filled with concrete, and long bolts were used from ring to ring on the circumferential joint. Finally, the rings inside the shield skins were grouted.

In order to make clear the nature of the work done in building these shield-driven tunnels in silt, a short description will be attempted, this description falling into three main divisions, namely, Shoving the Shield, Pushing Back the Jacks, and Erecting the Iron Lining.

Shoving the Shield.—This part of the work is naturally very important, as the position of the shield determines within pretty narrow limits the position of the iron built within it, hence the shield during its forward movement has to be guided very carefully. On this work certain instructions were issued for the guidance of the foreman in charge of the shield. These instructions were based on results of "checks" of the shield and iron's position by the engineering corps of the Company, and comprised, in the main, two requirements, namely, the leads that were to be got, and the quantity of muck to be taken in. The "lead" is the amount that the shield must be advanced further from the iron, on one side or the other, or on the top or bottom, as measured from the front face of the last ring of iron lining to the diaphragm of the shield. These leads are not necessarily true leads from a line at right angles to the center line, as the iron may have, and in fact usually does have, a lead of its own which is known and allowed for when issuing the requirements for the shove.

The foreman, knowing what was wanted, arranged the combination of shield jacks which would give the required leads and the amount of opening on the shield door which would give the required amount of muck. To see how the shield was going ahead, a man was stationed at each side at axis level and another in the crown. Each man had a graduated rod on which the marks were so distinct that they could be read by anyone standing on the lower platform. These rods were held against the shield diaphragm, and, as it advanced, its distance from the leading end of the last ring could be seen by the man in control of the jack valves. If he found that he was not getting the required leads, he could change the combination of jacks in action. As the time of a shove was often

less than 10 min., the man had to be very quick in reading the rods and changing the jacks. If it was found that extensive change in the jack arrangement was wanted, the shove could be stopped by a man stationed at the main hydraulic control valve; but, as any such stoppage affected the quantity of muck taken in, it was not resorted to unless absolutely necessary.

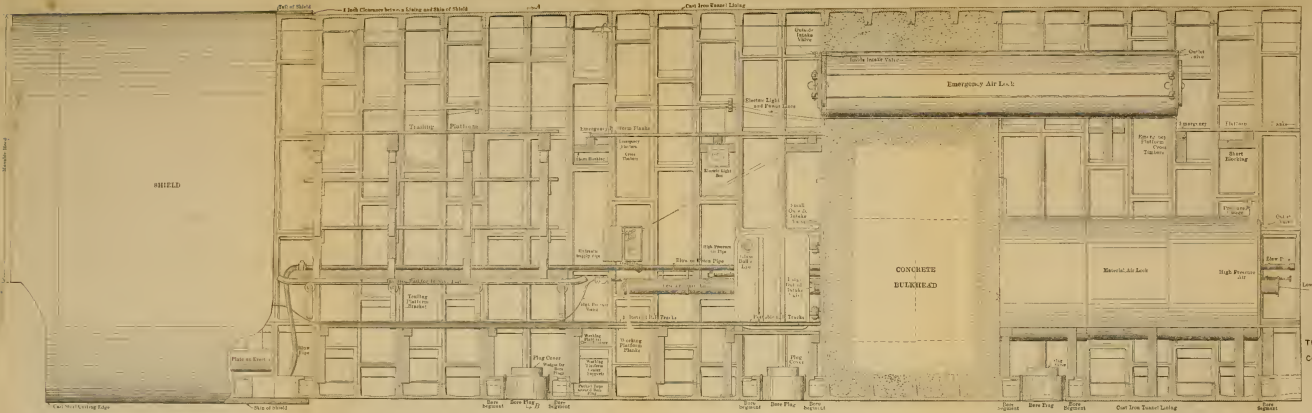
If the quantity of muck coming in was not as desired, a stop had to be made to alter the size of the opening, and if, while this was being done, the exhaust valves were not closed quite tight, the silt pressure on the face of the shield would force it back against the iron. This fact was sometimes taken advantage of when a full opening did not let in the desired quantity, for the shield could be shoved, allowed to return, and shoved again.

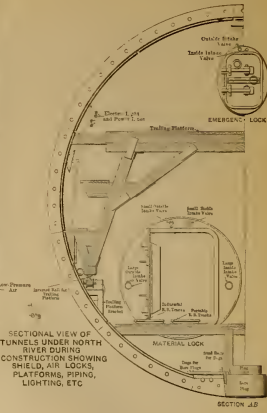
The time taken to shove in silt varied greatly with the quantity of material taken in; for shoving and mucking combined, it averaged 66 min., with an average of 13 cu. yd. of muck disposed of, or about 5 min. per cu. yd. of material.

Pushing Back the Jacks.—This was a simple matter, and merely consisted in making the loose push-back connection to each jack as it had to be sent back. Some of the jacks became strained and bent, and had to be taken out and replaced. Where there was silt pressure against the face of the shield, the hydraulic pressure had to be kept on until the ring was erected. In such cases, only two or three jacks could be pushed back at a time, and only after a segment had been set in position, and the pressure taken on it, could the next jack be pushed back, and so on around the ring. The time between the finish of the shove (hydraulic pres turned off) and the placing of the first segment, was occupied in pushing back the bottom jacks and cleaning dirt off the tail of the shield, and averaged about 14 min.

Erecting the Iron Lining.—As soon as the shove was over, the whole force, when in silt, set to work at building up the iron and then tightening the bolts so that the shield could be shoved again. A section of the tunnel with bolting and working platform is shown on Plate XL.

In the early part of the work, when the ground was being excavated ahead of the shield, the whole force, with the exception of those working in front of the shield, was engaged in erecting the





SECTIONAL VIEW OF TUNNELS UNDER NORTH RIVER DURING CONSTRUCTION SHOWING SHIELD, AIR LOCKS, PLATFORMS, PIPING, LIGHTING, ETC

iron, but, as soon as this was done, most of the men returned to the mucking, and only the iron workers continued to tighten up bolts. On the other sections, where the shield was shoved into the silt without excavating ahead, as soon as the shove was completed, the whole force was engaged in the erection of the iron and the tightening of the bolts, until they were so tight that the shield could be shoved again for another ring.

The iron was brought into the tunnel on flat cars, two segments to the car, and was lifted from the car and lowered into the invert of the shield by a block and fall and chain sling, as shown in Fig. 2, Plate XXXIX. The bottom three or four segments were pushed around into position with the erector, the head simply bearing against the longitudinal flange without being attached to the segment; the upper segments, however, were, as shown in Fig. 2, Plate XXXVIII, and Fig. 1, Plate XLI, attached to the erector, by using the expanding bar and the erector head designed by Mr. Patrick Fitzgerald, the Tunnel Superintendent. This was found to be a most convenient arrangement.

The single erector attached to the center of the shield was able to erect the iron as fast as it could be brought into the tunnel, and even when the weight of the segments was increased 25% (from 2 060 to 2 580 lb.) it always proved equal to its task, although occasionally one of the chains in the mechanism broke and delayed the work for an hour or so; but the sum of all the delays from this cause and from breaks and leaks in the hydraulic line only averaged 13 min. per ring. The operating valve which was first used was a four-spindle turning valve, but this was replaced by a sliding valve which was found to be much more satisfactory, both in case of operation and freedom from failure.

As the iron was put into place, two of the middle bolts in each longitudinal flange and two in each circumferential one were pulled as tight as possible, and the others put in loosely; then, as soon as the ring was in position, as large a force as could be conveniently worked at one time was engaged in tightening the bolts. The shape of the tunnel depended on the thoroughness of the tightening of the bolts, and the shield was never shoved until the bolts in all the longitudinal flanges had been thoroughly tightened. In addition, all the bolts in the circumferential flanges below the axis were tightened,

and at least three of the six in each segment above. After the shield had been shoved ahead, the bolts were found to have slackened, and, where the daily progress was four rings, or more, it was necessary to have a small gang of men always at this work.

In order to get at the bolts, special platforms were necessary, and throughout the greater part of the work, a traveling platform was used. This enabled the men to reach handily all parts of the seven leading rings. This platform was supported and moved forward on wheels fixed on brackets to the tunnel, and was pulled forward by connecting chains every time the shield was shoved. In the early part of the work it was not possible to use platforms, because, in order to maintain the correct circular shape of the iron lining, it was necessary to put in temporary horizontal turnbuckles at axis level. These, however, were very convenient for supporting the planks which were used as a temporary bolting platform for the sides of the tunnel, and a temporary platform resting on 6 by 6-in. timbers across the tunnel enabled the bolts in the crown of the tunnel to be reached, while the 6 by 6-in. timbers were left in to support the emergency platform previously described (Plate XL), which extended the entire length of the tunnel.

The time taken to erect the iron lining became shorter and shorter as the tunnel organization became more perfect and the force better trained, so that, whereas, in the early part of the work, it frequently took 6 hours to erect a ring, in the latter part, when the work was nearing completion, it was a common occurrence to erect a ring in 30 min. The average time in the "heavy iron" section, which included the greater part of the work under the river, was 1 hour 4 min. for the erection of the ring and 40 min. for tightening the bolts after that had been completed, so that the total time spent by the whole gang on erection and bolting averaged 1 hour 44 min. per ring, exclusive of the time spent by the small gang which was always engaged in tightening the bolts. The average time spent in erecting and bolting, for the whole length of the tube tunnels, was 2 hours 15 min. per ring.

Tables of Progress.—Tables 24, 25, 26, and 27 have been prepared to show the time taken in the various operations at each working face.

A 45. P. R. R. Tunnels, N. R. Div. Section Gy West
River Tunnel South Manhattan. Putting in key segment.
Sept. 11, 08.

FIG. 1.

A 132. P. R. R. Tunnels, N. R. Div. Sect. Gy West (South Tunnel)
Method of grouting outside iron lining. May 12, 09.

FIG. 2.

In Tables 24, 25, 26, and 27, the following symbols are used:

A—Including assistant superintendents, foremen, and electricians, in driving the shield, erecting iron, mucking, attending to the electric lights, and repairing the pipe line.

B—Drillers, drillers' helpers, drill foremen, and nippers.

C—All men grouting.

D—Engineers and laborers wholly employed on transport between the first lock and the face.

E—In rock, one car = 0.60 cu. yd.; in sand or silt = 1.20 cu. yd. in place.

F—Time between completion of mucking and putting in first plate, spent in shoving the jacks back.

G—In ordinary iron = the whole time spent on erection and bolting. In heavy iron = the time between putting in the first plate and placing the key only.

H—Time between placing the key and starting the next shove, spent by the whole gang in tightening bolts. In addition to this, there was a small gang which spent its whole time at this work.

I—In Table 24 the first pair of bore segments is at ring 207-208.
" " 25 " " " " " " " " " " 201-202.
" " 26 " " " " " " " " " " 185-186.
" " 27 " " " " " " " " " " 171-172.

Outside diameter of tunnel = 23 ft. 0 in.
Inside " " " = 21 ft. 2 in.
Length of ring = 2 ft. 6 in.

In the "Ordinary Iron" section the time is divided between mucking (which included the shoving and pushing back of the jacks) and the erection time (which included the time spent by the whole gang in tightening bolts). In the "Heavy Iron" section these times are all separated into "Mucking," "Pushing Back Jacks," "Erecting," and "Bolting," and here the bolting time included only that spent on bolts by the whole gang; in addition, there was a small gang engaged solely in tightening bolts. The lost time is the average time lost due to the break-down of hydraulic pipe lines, damaged jacks, and broken erector chains. The erection time is separated for the various kinds of rings, that is, straight ordinary rings, rings con-

TABLE 24.—SHIELD-DRIVEN TUNNEL WORK,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Ave. air pressure.	Method of excavation.	Ave. No. of Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Av. No. of cu. yd. per ring. E	Time mucking, per cu. yd.
Ordinary.	1–54	135.0	Rock	0	‡	....	....	....	....	14	....	....
	55–80	65.0	"	19	‡	24	7	3/4	1	32	41	0–31
	81–106	65.0	Soft rock	18	‡	22	5	....	2	29	41	0–33
	107–153	117.5	Rock	14	‡	17	11	....	2	30	41	0–39
	154–194	102.5	Rock and earth	14	‡	23	6	....	2	31	41	0–37
	195–215	52.5	Silt	19	‡ Breasting	28	....	....	2	30	41	0–10
	216–393	445.0	"	20	§ 8 doors	27	....	....	4	31	46	0–5
	394–429	90.0	Silt, piles, rip-rap	24	‡ Breasting	28	....	....	4	32	46	0–18
	430–509	200.0	Silt	23	§ 1 door	24	....	....	3	27	11	0–10
	510–692	457.5	"	23	§ 3 doors	26	....	....	4	30	20	0–5
	55–692	1 595.0	.....	20	.....	25	2	....	3	30	30	0–15
	216–692	1 192.5	.....	22	.....	26	....	....	4	30	30	0–07
Heavy.	693–954	655.0	Silt	24	§ 1 door	28	....	....	6	34	11	0–12
	955–1 014	150.0	"	24	§ 1 "	28	....	....	8	36	12	0–4
	1 015–1 074	150.0	"	24	§ 1 "	25	....	....	8	33	12	0–3
	1 075–1 134	150.0	"	24	§ 1 "	27	....	....	9	36	8	0–4
	1 135–1 194	150.0	"	25	§ 1 "	26	....	....	8	34	8	0–4
	1 195–1 224	75.0	"	25	§ 1 "	24	....	....	9	33	6	0–4
	1 225–1 262	95.0	"	25	§ 1 "	23	....	....	9	32	5	0–5
	1 263–1 277	37.5	"	25	§ 1 "	24	....	....	10	34	10	0–4
	1 278–1 307	75.0	"	25	§ 1 "	21	....	....	10	31	17	0–4
	1 308–1 326	47.5	"	28	§ 1 "	27	....	....	11	38	22	0–5
	955–1 326	930.0	.....	24	.....	26	....	....	9	35	11	0–4
	693–1 326	1 585.0	.....	24	.....	27	....	....	8	35	12	0–4
All.	216–1 326	2 777.5	.....	23	.....	27	....	....	7	34	19	0–6
	55–1 326	3 180.0	.....	22	.....	26	....	....	6	32	21	0–10

SUM

Weight of iron.	Section between rings.	Description. Length, in feet.	Material.	Ave. air.	Method of excavating.	Average No. of Men in Gang. Shield.	Drilling.	Grouting.	Air Trans.	Total.
Ordinary.	1–54	135.0	Rock	0	‡	.....	.....	....	.....	14
	55–194	350.0	Earth and rock	16	‡	22	6	1/2	2	30
	195–393	497.5	Silt	20	‡ Breasting	25	.....	....	4	31
	394–440	117.5	"	24	‡ Breasting	28	.....	....	4	32
	441–692	630.0	"	23	§ 3 doors	25	.....	....	4	29
	216–692	1 192.5	.....	22	.....	26	.....	....	4	30
	55–692	1 595.0	.....	20	.....	25	2	....	3	30
Heavy.	693–1 326	1 585.0	Silt	24	§ 1 door	27	.....	....	8	35
All	55–1 326	3 180.0	.....	22	.....	26	.....	....	6	32

*Including time for jacks. †Including bolting time. ‡Excavating ahead of shield.

Manhattan Shaft, River Tunnel North.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Av. time per ring, shoving and mucking.	Time for jacks.	Time for Ring Erection, Hrs. and Min.					Bolting Time, Whole Time on Bolts After Ring is Complete.					Time lost repairing hydraulic piping.	Total Time.				
		Ordin'ry.	Bore 1.	Bore 2.	Taper.	Mean.	Ordin'ry.	Bore 1.	Bore 2.	Taper.	Mean.		Ordinary.	Bore 1.	Bore 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
.....		4-0	.....	.....	4-21	4-4	Excavation partially completed previously.										
21-0		6-4	.....	.....	5-30	5-57						.....	27-4	.....	.....	26-30	26-57
32-30		4-26	.....	.....	.....	4-26						.....	26-56	.....	.....	.....	26-56
26-31		3-10	.....	.....	3-30	3-12						.....	29-41	.....	.....	30-1	29-43
18-34		3-08	J.	J.	3-40	2-10						.....	20-42	.....	.....	21-14	20-44
6-46		3-03	3-30	3-30	.....	3-09						.....	9-49	10-16	10-16	.....	9-55
3-53		3-40	2-56	3-00	3-10	2-50						0-9	6-42	6-58	7-02	7-12	6-52
17-09	Time for jacks for light iron is included in shoving and mucking.	3-43	3-39	4-46	4-11	3-56	Bolting time for light iron is included in erection.					2-37	23-79	23-25	24-32	23-57	23-42
1-42		3-11	4-12	3-59	3-46	3-34						0-18	5-14	6-12	5-59	5-46	5-34
1 47		2-08	2-21	2-32	2-50	2-18						0-11	4-06	4-19	4-30	4-48	4-16
7-35	*	3-02	.....	.....	4-31	3-12						0-17	10-54	.....	.....	12-23	11-04
3-42	*	2-38	2-59	3-08	1-30	2-50						0-25	6-45	7-06	7-15	5-37	6-57
1-02	*	1-52	2-05	2-15	2-29	2-0						0-13	3-7	3-20	3-30	3-44	3-15
0-48	0-16	0-51	1-18	1-8	0-50	0-58	0-24	0-21	0-37	0-10	0-25	0	2-19	2-43	2-49	2-04	2-27
0-41	0-13	0-43	0-46	0-55	0-40	0-45	0-31	0-30	0-52	0-23	0-34	0-2	2-10	2-12	2-43	1-59	2-15
0-34	0-12	1-4	1-1	1-15	1-20	1-08	0-28	0-35	1-40	0-52	0-44	0-3	2-21	2-25	3-44	3-01	2-41
0-33	0-13	0-53	0-51	0-58	0-46	0-53	0-32	0-20	0-24	0-18	0-26	0	2-11	1-57	2-08	1-50	2-05
0-24	0-12	0-58	0-42	0-53	0-50	0-54	0-19	0-20	0-34	0-35	0-23	0	1-53	1-38	2-03	2-01	1-53
0-23	0-10	0-48	0-49	0-50	0-35	0-47	0-29	0-29	0-36	0-18	0-30	0	1-50	1-51	1-59	1-26	1-50
0-36	0-11	0-47	0-50	0-52	0-48	0-52	0-23	0-23	0-41	0-23	0-27	0	1-57	2-0	2-20	1-58	2-06
1-09	0-10	1-3	1-01	1-06	0-0	1-04	0-33	0-34	0-51	0-0	0-36	0	2-55	2-54	3-16	0-0	2-59
1-39	0-18	1-25	1-48	1-50	0-50	1-31	0-19	0-42	0-58	0-25	0-48	0	4-11	4-27	4-45	3-12	4-16
0-41	0-13	0-55	0-59	1-03	0-55	0-58	0-29	0-27	0-49	0-31	0-32	0	2-18	2-20	2-46	2-20	2-24
0-51	*	1-27	1-34	1-41	1-38	1-31	†	.....	.....	.....	.....	0-6	2-24	2-31	2-38	2-35	2-28
1-59	*	1-55	2-08	2-16	1-35	2-03	†	.....	.....	.....	.....	0-16	.....	.....	.....	.....	4-18
4-13	*	.....	.....	.....	.....	2-22	†	.....	.....	.....	.....	0-12	.....	.....	.....	.....	6-47

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring.				Unavoidable Delays (not Included in Average Time per Ring).		
		Shoving and mucking. *	Erection. †	Lost time.	Total.	Items.	Time. hrs.	min.
.....	.....	.....	4-14	.....	.....	First bulkhead.....	172	00
41	0-32	21-44	4-4	.....	25-48	Second bulkhead.....	119	00
38	0-7	4-11	2-52	0-9	7-12	Grouting.....	200	00
41	0-18	11-54	4-17	1-41	17-52	Blowout.....	73	00
17	0-6	2-04	2-34	0-42	5-20	Cradle.....	100	00
30	0-7	3-42	2-50	0-25	6-57	Total.....	664	00
30	0-15	7-35	3-12	0-17	11-04	Per ring.....	0	30
12	0-4	0-51	1-31	0-06	2-28			
21	0-10	4-13	2-22	0-12	6-47			

§ Shoving shield into silt with....doors open.

TABLE 25.—SHIELD-DRIVEN TUNNEL WORK,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Av. air pressure.	Method of excavation.	Average No. Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Av. No. of cu. yd. per ring. E	Time mucking, per cu. yd.
Ordinary.	1–68	170.0	Rock.....	0	*	20	5	5	2	32	41	0·14
	69–95	67.5	Rock and earth...	13	*	22	8	....	2	32	41	0–24
	96–141	115.0	Rock.....	10	*	21	13	....	2	36	70	0–16
	142–191	125.0	Rock and earth..	15	*	24	7	....	2	33	52	0–20
	192–203	30.0	Silt.....	18	*Breasting.	23	....	....	3	26	36	0–13
	204–388	462.5	"	18	†7 doors.	27	....	....	3	30	37	0–05
	389–429	102.5	Silt, piles and rip-rap.....	22	†6 doors. *Breasting.	24	....	....	4	28	40	0–17
	430–504	187.5	Silt.....	21	†3 doors.	23	....	....	5	28	20	0–06
	505–629	312.5	"	22	†4 doors.	25	....	....	6	31	27	0–05
	630–692	157.5	"	23	†2 doors.	24	....	....	8	32	32	0–05
	204–692	1 222.5	.....	21	.....	25	....	....	5	30	30	0–07
	69–692	1 560.0	.....	17	.....	23	4	0	3	30	36	0–11
Heavy.	693–766	185.0	Silt.....	24	†2 doors.	21	....	....	6	27	22	0–05
	767–866	100.0	"	24	†2 "	22	....	....	7	29	22	0–05
	867–900	235.0	"	24	†1½ "	23	....	....	8	31	19	0–05
	901–933	82.5	"	25	†1 door.	30	....	....	10	40	19	0–04
	934–988	137.5	"	25	†1 "	30	....	....	11	41	16	0–04
	989–1 043	137.5	"	25	†1 "	28	....	....	11	39	13	0–05
	1 044–1 053	25.0	"	26	†1 "	25	....	....	9	34	16	0–07
	1 054–1 068	37.5	"	26	†1 "	26	....	....	9	35	8	0–05
	1 069–1 110	105.0	"	26	†1 "	30	....	....	11	41	13	0–06
	693–1 110	1 045.0	.....	25	.....	25	....	....	8	33	18	0–05
All.	204–1 110	2 267.5	.....	23	.....	25	....	....	6	31	25	0–06
	69–1 110	2 605.0	.....	20	.....	24	2	....	5	31	29	0–09

SUM

Weight of iron.	Section between rings	Description. Length, in feet.	Material.	Av. air pres.	Method of excavation.	Average No. of Men in Gang. Shield.	Drilling.	Grout-ing.	Air trans.	Total.
Ordinary.	1–68	170.0	Rock.....	0	*.....	20	5	5	2	32
	69–191	307.5	Rock and earth..	13	*.....	22	9	....	2	33
	192–388	492.5	Silt.....	18	*Breasting. †7 doors....	25	.....	....	3	28
	389–429	102.5	Silt, piles and rip-rap.	22	*Breasting.. †6 doors....	24	.....	....	4	28
	430–692	657.5	Silt.....	22	†3 doors....	24	.....	....	6	30
	204–692	1 222.5	.....	21	.....	25	.....	....	5	30
	69–692	1 560.0	.....	17	.....	23	4	0	3	30
Heavy.	693–1 110	1 045.0	.....	25	† 1 door	25	.....	....	8	33
All.....	69–1 110	2 605.0	.....	20	.....	24	2	....	5	31

* Excavating ahead of shield. † Shoving shield into silt with.....doors open.

Manhattan Shaft, River Tunnel South.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Av. time per ring, shoving and mucking.	Time for jacks.	Time for Ring Erection. Hrs. and Min.					Bolting Time, Whole Time on Bolts After Ring is Complete.					Time lost repairing hydraulic fitting	Total Time.				
		Ordin.	Bore 1.	Bore 2.	Taper.	Mean.	Ordin.	Bore 1.	Bore 2.	Taper.	Mean.		Ordin.	Bore 1.	Bore 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
9–53		5–27	....	....	4–32	5–07	Excavation partially completed previously.					....	15–20	.....	.....	14–25	15–00
16–18		3–02	....	....	2–40	3–00						....	19–20	.....	.....	18–58	19–18
18–16		3–08	....	....	2–27	2–09						0–03	20–27	.....	.....	20–46	20–28
17–27		3–08	J	J	2–04	2–08						0–12	19–47	.....	.....	19–43	19–47
7–58		3–27	0–40	2–10	3–15	2–47	Bolting time for light iron is included in erection.					1–20	11–45	15–18	11–28	12–33	12–05
9–19		2–41	2–49	2–54	2–56	2–47						0–05	6–05	6–13	6–18	6–20	6–11
12–42		3–15	2–36	5–03	3–26	3–27						0–38	16–35	15–56	18–23	16–46	16–47
1–51	Time for jacks for light iron is included in shoving and mucking.	2–53	3–17	3–00	2–57	2–59						0–39	5–23	5–47	5–30	5–27	5–29
2–20		2–23	2–40	2–45	2–28	2–30						0–23	5–06	5–23	5–28	5–11	5–13
1–53		1–54	2–10	2–22	2–23	2–02						0–08	3–55	4–11	4–23	4–24	4–03
3–27	†††	2–34	2–45	2–58	2–35	2–42						0–18	6–19	6–30	6–43	6–20	6–27
6–40		2–47	....	....	3–18	2–52						0–15	9–42	.....	.....	10–13	9–47
1–35	0–25	1–18	1–44	1–30	1–40	1–25	0–43	1–09	0–52	0–50	0–49	0–07	4–08	5–00	4–29	4–37	4–21
1–19	0–21	1–00	0–56	1–37	1–21	1–08	0–38	0–24	0–43	0–38	0–42	0–02	3–20	3–02	4–02	3–41	3–32
1–11	0–17	0–58	1–13	1–08	1–12	1–04	0–39	0–34	0–56	0–31	0–40	0–06	3–11	3–21	3–38	3–17	3–18
1–13	0–09	0–59	1–05	0–59	....	1–00	0–34	0–26	1–47	....	0–43	0–05	3–00	2–58	4–13	....	3–10
0–54	0–12	0–49	0–44	0–56	....	0–50	0–28	0–34	0–34	....	0–30	0–06	2–29	2–30	2–42	.....	2–32
0–52	0–14	0–51	0–44	0–52	1–14	0–52	0–33	0–24	0–51	0–35	0–35	0–04	2–34	2–18	2–53	2–59	2–37
1–40	0–15	1–04	1–15	0–50	0–55	1–02	0–23	0–38	0–30	0–55	0–36	...	3–22	3–48	3–15	3–45	3–33
0–36	0–08	0–57	0–40	1–02	....	0–56	0–33	0–25	0–35	....	0–32	....	2–14	1–49	2–21	....	2–12
1–00	0–15	0–48	0–54	1–06	1–31	0–56	0–32	0–40	0–48	0–46	0–37	0–05	2–40	2–54	3–14	3–37	2–53
1–29	‡	1–01	1–08	1–09	1–19	1–05	0–37	0–39	0–52	0–40	0–40	0–05	3–12	3–21	3–35	3–33	3–19
2–35	‡	2–09	2–19	2–33	2–19	2–17	§	....	....	....	....	0–12	4–56	5–06	5–20	5–06	5–04
4–36	†††	2–19	....	....	2–46	2–25	§	....	....	....	....	0–14	7–09	.....	.....	7–36	7–15

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring.				Unavoidable Delays (not Included in Average Time per Ring).		
		Shoving and mucking. ‡	Erection. §	Lost time.	Total.	Items.	Time. hrs.	min.
41	0–14	9–53	5–07	.....	15–00	First bulkhead	160	00
54	0–19	17–20	2–26	0–05	19–51	Second bulkhead	157	45
37	0–09	5–39	2–47	0–63	9–29	Grouting	264	00
40	0–17	12–42	3–27	0–38	16–47	Blowout	69	45
24	0–05	1–58	2–29	0–22	4–49	Waiting for heavy iron	64	00
30	0–07	3–27	2–42	0–18	6–27	Total	715	30
36	0–11	6–40	2–52	0–15	9–47	Per ring	0	39
18	0–05	1–29	1–45	0–05	3–19			
29	0–09	4–36	2–25	0–14	7–15			

‡ Including time for jacks. § Including bolting time.

TABLE 26.—Shield-Driven Tunnel Work,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Ave. air pressure.	Method of excavation.	Ave. No. of Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Ave. No. of cu. yds. per ring. E	Time mucking, per cu. yd.
Ordinary.	1–24	60	Rock	0	‡	9	0.04	0	0	10	46	0–06
	25–55	77.5	"	20	‡	14	5	0.5	1	21	46	0–51
	56–72	42.5	Mixed sand and rock	10	‡ Breast'g.	22	2	0.09	2	26	44	0–21
	73–165	232.5	Sand and gravel	10	"	22	0	0.1	2	24	39	0–11
	166–184	47.5	Sand and silt with piles.	20	‡Breast'g and cutting piles	22	0	0.38	3	25	42	0–09
	185–253	172.5	Silt and piles	24		23	0	0.71	3	26	43	0–09
	254–293	100.0	Silt	26	§ 8 doors	22	0	0	3	25	6	0–18
	294–301	20.0	"	27		19	0	0	2	21	0	0
	302–307	15.0	"	27	§ 8 doors	21	0	0	2	23	26	0–09
	308–342	87.5	"	25		19	0	0	2	21	0	0
	343–347	12.5	"	28	§ 8 doors	15	0	0	2	17	2	0–36
	348–459	280.0	"	28		20	0	0	3	23	0	0
	460–494	87.5	"	28	§ 8 doors	21	0	0	3	24	9	0–09
	495–513	47.5	"	28	8 "	23	0	0	4	27	17	0–05
	514–605	230.0	"	28	8 "	25	0	0	4	29	26	0–04
	606–624	47.5	"	28	8 "	24	0	0	4	28	16	0–04
	625–640	40.0	"	28	8 "	38	0	0	5	43	24	0–03
	25–640	1 540.0		20								
	185–640	1 140.0		26		23	0	0.2	3	26	16	0–07
Heavy.	641–647	17.5	Silt	28	§ 8 doors	24	0	0	6	30	19	0–04
	648–751	260.0	"	28	8 "	22	0	0	4	26	14	0–03
	752–795	110.0	"	28	8 "	18	0	0	7	25	10	0–03
	796–825	75.0	"	28	8 "	19	0	0	10	28	5	0–08
	826–854	72.5	"	28	8 "	17	0	0	3	20	15	0–03
	855–881	67.5	"	28	8 "	23	0	0	9	32	7	0–05
	882–982	252.5	"	28	8 "	20	0	0	8	28	10	0–02
	983–990	20.0	"	28	8 "	21	0	0	7	28	17	0–02
	991–1 049	147.5	"	28	8 "	23	0	0	7	30	8	0–03
	1 050–1 074	62.5	"	28	8 "	24	0	0	9	33	7	0–03
	1 075–1 110	90.0	"	28	8 "	25	0	0	10	35	16	0–02
	641–1 110	1 175.0		28		21	0	0	7	28	8	0–04
All.	185–1 110	2 315.0		28		22	0	0.1	5	27	12	0–07
	25–1 110	2 715.0		26		21	0.1	0.1	3	24	17.1	0–12

SUM

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Ave. air.	Method of excavation.	Average No. of Men in Gang. Shield.	Drilling.	Grouting.	Air trans.	Total.
Ordinary.	1–24	60.	Rock	0	‡	9	0.04	0	0	10
	25–55	77.5	"	20	‡	14	5	0.5	1	21
	56–72	42.5	Mixed sand and rock	10	‡Breasting.	22	2	0.09	2	26
	73–165	232.5	Sand and gravel.	10	‡Breasting.	22	0	0.1	2	24
	166–184	47.5	Sand and silt with piles.	20	‡Breasting and cutting piles.	22	0	0.38	3	25
	185–253	172.5	Silt with piles.	24		23	0	0.71	3	26
	254–640	100.0	Silt	26	§Doors.	22	0	0	3	25
	25–640	1 540.0		20	§Doors.	21	0.3	0.12	3	24
Heavy.	641–1 110	1 175.0		28		21	0	0	7	28
All.	25–1 110	2 715.0		26		21	0.1	0.1	3	24

* Including time for jacks. † Including bolting time.

Weehawken Shaft, River Tunnel North.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Av. time per ring, shoving and mucking.	Time for jacks.	Time for Ring Erection. Hrs. and Min.					Bolting Time, Whole Time on Bolts After Ring is Complete.					Time lost repairing hydraulic fitting.	Total Time.				
		Straight.	Bore No. 1.	Bore No. 2.	Taper.	Mean.	Straight.	Bore No. 1.	Bore No. 2.	Taper.	Mean.		Straight.	Bore No. 1.	Bore No. 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
4–32		6–23	....	....	....	6–23	Excavation partially completed previously.					....	10–55			.....	10–55
39–33		4–25	....	....	5–10	4–29						....	43–58	.....	.....	44–43	44–02
15–05		2–53	....	....	3–15	2–55						0–04	18–02	.....	.....	18–24	18–04
6–56		2–27	....	....	2–21	2–26						0–09	9–32	.....	..	9–26	9–31
6–19		2–31	J	J	6–30	2–37						0–07	8–57	.....	.....	12–56	9–03
6–13		1–57	2–44	2–52	2–00	2–15						0–15	8–25	9–12	9–20	8–28	8–43
1–45		1–58	1–57	2–15	2–45	2–02						0–14	3–57	3–56	4–14	4–44	4–01
1–08		0–58	1–45	1–50	....	1–17						....	2–06	2–53	2–58	.....	2–25
4–03		2–30	1–40	1–55	2–57	2–22						....	6–23	5–43	5–58	7–00	6–25
0–36	Time for jacks for light iron is included in shoving and mucking.	2–00	1–34	2–42	1–53	2–02	Bolting time for light iron is included in erection.					....	2–36	2–10	3–18	2–29	2–38
1–11		2–15	2–20	....	2–43	2–33						0–39	4–05	4–10	.....	4–43	4–23
0–33		2–08	2–04	2–09	2–23	2–06						0–14	2–50	2–51	2–56	3–10	2–53
1–23		2–49	2–30	2–50	1–50	2–38						0–27	4–39	4–20	4 40	3–40	4–28
1–42		2–35	2–23	1–55	2–10	2–26						....	4–03	3–51	3–23	3–38	3–54
1–44		2–12	2–34	2–29	2–15	2–19						....	3–56	4–18	4–13	3–59	4–03
1–07		1–54	2–33	2–16	1–35	2–04						....	3–01	3–40	3–23	2–42	3–11
1–13	.....	2–14	2–55	2–35	2–16	2–28						....	3–27	4–08	3–48	3–59	3–41
.....	.....	.....	.....	.....	.....	.....						.....	.....	.....	.....	.....	.....
1–58	*	2–07	2–19	2–26	2–15	2–13						0–09	4–14	4–26	4–33	4–22	4–20
1–08	*	1–20	2–08	1–65	1–40	1–41	0–40	0–35	1–25	0–55	0–47	....	3–08	3–51	4–28	3–43	3–36
0–36	0–12	1–21	1–32	1–26	1–55	1–23	0–31	0–29	0–38	0–30	0–32	0–12	2–52	2–51	3–04	3–25	2–55
0–23	0–14	0–46	1–25	1–31	2–37	1–10	0–48	0–31	0–44	0–35	0–43	0–05	2–22	2–44	3–03	4–00	2–41
0–40	0–11	0–48	1–31	1–34	0–53	1–03	0–31	1–03	0–49	0–27	0–51	....	2–10	3–25	3–14	5–11	2–45
0–48	0–19	0–54	1–12	1–02	1–23	1–01	0–22	0–37	0–38	0–20	0–27	0–06	2–29	3–02	2–53	2–56	2–41
0–33	0–16	0–59	0–45	1–15	1–29	1–01	0–22	0–21	0–45	0–40	0–26	0–45	2–55	2–40	3–34	3–34	3–01
0–20	0–14	0–49	1–02	1–01	0 50	0–54	0–41	0–36	0–36	0–15	0–39	0–12	2–16	2–24	2–23	1–51	2–19
0–34	0–14	0–40	0–40	0–48	....	0–44	1–15	0–15	0–28	....	0–48	....	2–43	1–43	2–04	.....	2–20
0–21	0–11	0–40	0–48	0–39	....	0–41	0–41	0–34	0–55	....	0–41	....	1–58	1–54	2–06	.....	1–54
0–18	0–10	0–43	0–44	0–46	0–40	0–43	0–35	1–15	1–07	0–35	0–48	0–04	1–50	2–31	2–25	1–47	2–03
0–33	0–12	0–50	1–02	1–06	0–58	0–55	0–35	0–46	0–58	2–10	0–41	0–21	2–31	2–54	3–10	4–14	2–42
0–30	0–11	0–56	1–08	1–12	1–29	1–02	0–36	0–36	0–44	0–54	6–38	0–11	2–27	2–39	2–51	3–18	2–35
1–20	0*	1–48	2–01	2–11	2–17	1–56	+	...	....	.....	.....	0–10	3–18	3–31	3–41	3–47	3–26
3–13	*	....	.....	.....	.....	2–05	†	.....	.....	.....	.....	0–09	.....	*	.....	.....	5–27

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring.				Unavoidable Delays (not Included in Average Time per Ring).		
		Shoving and mucking. *	Erection. †	Lost time.	Total.	Items.	Time, hrs.	min.
46	0–06	4–32	6–23	0	10–55	First bulkhead	132	00
46	0–51	39–33	4–29	0	44–02	Second bulkhead	158	50
						Grouting	240	00
44	0–21	15–05	2–55	0–04	18–04	Old cave-in	234	00
39	0–11	6–56	2–26	0–09	9–31	Shoving tube	128	00
42	0–09	6–19	2–37	0–07	9–03	Total	892	50
43	0–09	6–13	2–15	0–15	8–43	Per ring	0	49
11	0–07	1–13	2–20	0–08	3–41			
24	0–14	5–06	2–24	0–08	7–38			
8	0–04	0–44	1–40	0–11	2–35			
17.1	0–12	3–13	2–05	0–09	5–27			

‡ Excavating ahead of shield. § Shoving shield into silt with.....doors open.

TABLE 27.—Shield-Driven Tunnel Work,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length, in feet.	Material.	Ave. air pressure.	Method of excavation.	Ave. No. of Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Ave. No. of cu. yd. per ring. E	Time mucking, per cu. yd.
Ordinary.	1–27	67.5	Rock	9	‡	Excavation partially completed previously.						
	28–42	37.5	"	12	‡	13	4	1	1	19	48.7	0–25
	43–58	40.0	Rock or gravel	12	‡	19	2	2	2	25	44.2	0–46
	59–153	237.5	Gravel and sand	16	‡ Breast'g.	25	...	1	4	30	39.0	0–12
	154–170	42.5	Sand and silt with piles.	18	"	26	...	1	5	32	41.6	0–10
	171–236	165.0	Silt with piles	22	Top half	22	...	1	3	26	42.6	0–10
	237–259	57.5	Silt	25	§ 1 door	18	...	1	3	22	13.8	0–11
	260–302	107.5	"	27	§ 1 "	15	...	...	2	17	0	....
	303–350	120.0	"	27	§ 8 doors	15	...	...	4	19	6.9	0–07
	351–378	70.0	"	27½	§ 8 "	18	...	...	6	24	0	....
	379–424	115.0	"	27½	§ 8 "	19	...	...	4	23	6.9	0–07
	425–522	245.0	"	28	§ 1 door	19	...	...	4	23	6.7	0–06
	523–625	257.5	"	28	§ 1 "	20	...	...	4	24	0	....
	171–625	1 137.5		27		19	...	...	4	23	9.7	0–11
	28–625	1 495.0		25		19	0.8	0.8	3.4	24	17.8	0–14
Heavy.	626–649	57.5	Silt	28	§ 1 door	16	...	...	3	19	12.2	0–12
	650–733	210.0	"	28	§ 8 doors	19	...	...	4	23	13.5	0–04
	734–753	50.0	"	28	§ 8 "	24	...	...	5	29	8.3	0–05
	754–844	227.5	"	28	§ 8 "	26	...	...	8	34	12.8	0–04
	845–859	37.5	"	28	§ 8 "	27	...	...	9	36	5.6	0–07
	860–899	100.0	"	28	§ 8 "	24	...	...	8	32	16.5	0–02
	900–935	90.0	"	28	§ 1 door	25	...	...	7	32	11.5	0–03
	936–963	70.0	"	28	§ 1 "	25	...	...	8	33	5.9	0–03
	964–1 003	100.0	"	28	§ 1 "	25	...	...	10	35	8.1	0–03
	1 004–1 060	142.5	"	28	§ 1 "	26	...	...	10	36	8.7	0–03
	1 061–1 110	125.0	"	28	§ 1 "	37	...	...	10	47	6.2	0–03
	1 111–1 238	320.0	"	28	§ 1 "	30	...	...	9	39	15.6	0–02
	1 239–1 312	185.0	"	28		39	...	...	9	38	13.0	0–03
	626–1 312	1 717.5	"	28		25	...	...	8	33	10.6	0–04
All.	171–1 312	2 855.0		28		23	...	...	6	29	10.2	0–07
	28–1 312	3 212.5		26		21	...	...	5	26	14.1	0–10

SUM

Weight of iron.	Section between rings.	Description. Length, in feet.	Material.	Ave. air.	Method of excavation.	Aver. No. of Men in Gang. Shield.	Drilling.	Grouting.	Air transport.	Total.
Ordinary.	28–42	37.5	Rock	12	‡Breast	13	4	1	1	19
	43–58	40.0	Rock and gravel	12	"	19	2	2	2	25
	59–153	237.5	Gravel and sand	16	"	25	....	1	4	30
	154–170	42.5	Sand or silt, with piles	18	"	26	....	1	5	32
	171–236	165.0	Silt, with piles	22	"	22	....	1	3	26
	237–259	57.5	Silt	25	§ 1 door	18	....	1	3	22
	260–625	915.0	"	27	1 "	18	....	....	4	22
	28–625	1 495.0		25		19	0.8	0.8	3.4	24
Heavy.	626–1 312	1 717.5	Silt	28		25	....	....	8	33
All.	28–1 312	3 212.5		26		21	....	....	5	26

* Including time for jacks. † Including bolting time.

Weehawken Shaft, River Tunnel South.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Ave. time per ring, shoving and mucking.	Time for jack.	Time for Ring Erection, Hrs. and Min.					Bolting Time (Whole Time on Bolts after Ring is Complete).					Time lost repairing hydraulic fittings.	Total Time.				
		Straight.	Bore 1.	Bore 2.	Taper.	Mean.	Straight.	Bore 1.	Bore 2.	Taper.	Mean.		Straight.	Bore 1.	Bore 2.	Taper,	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
.....	....	8-30	....	....	3-45	8-08	Bolting time for light iron is included in erection.					0-14	21-11	.....	.....	16-26	20-49
20-33	....	4-23	....	....	4-00	4-21						0-12	25-08	.....	.....	24-45	25-06
33-44	....	4-16	....	....	5-45	4-44						1-15	39-15	.....	.....	40-44	39-43
8-06	....	2-19	....	....	4-18	2-23						0-30	10-55	.....	.....	12-54	10-59
7-10	....	2-00	J.	J.	1-48	1-59						0-0	9-10	J.	J.	8-58	9-09
7-23	....	2-36	2-55	2-58	1-24	2-35						0-05	10-04	10-23	10-26	8-52	10-03
2-29	....	3-01	2-05	1-28	2-00	2-32						0-20	5-50	4-54	4-17	4-49	5-21
0-32	....	2-34	2-35	3-38	4-28	3-05						0-08	3-14	3-15	4-18	5-08	3-45
0-52	....	2-59	2-28	2-37	1-44	2-41						0-07	3-58	3-27	3-36	2-13	3-40
0-33	....	2-05	2-32	2-48	2-00	2-18						0-17	2-55	3-22	3-38	2-50	3-08
0-18	....	3-34	2-51	3-18	3-19	3-22						0-25	4-47	4-09	4-31	4-32	4-35
0-15	....	3-09	3-51	3-00	3-28	3-16						0-16	4-10	4-52	4-01	4-29	4-17
0-32	....	1-36	1-37	1-47	1-51	1-39						0-12	2-20	2-21	2-31	2-35	2-23
1-44	*	2-37	2-41	2-41	2-32	2-38						0-13	4-34	4-38	4-38	4-29	4-35
4-14	*	....	....	....	....	2-41						0-16	.....	.....	.....	.....	7-11
2-23	*	2-19	2-30	2-05	1-42	2-16	1-01	1-04	1-04	0-50	1-01	0-32	6-15	6-29	6-04	5-27	6-12
0-57	0-13	1-42	1-21	1-47	1-48	1-39	1-15	0-52	0-55	0-42	1-07	0-32	4-39	3-58	4-24	4-12	4-28
0-41	0-17	1-06	1-55	0-38	1-20	1-12	0-58	0-44	1-13	0-20	0-44	0-06	2-48	3-43	2-55	2-44	3-00
0-51	0-16	1-19	1-41	1-52	0-50	1-29	0-39	0-50	0-54	0-40	0-44	0-25	3-30	4-03	4-18	3-02	3-45
0-39	0-19	1-24	1-08	1-10	....	1-20	0-45	0-15	0-15	....	0-37	0-48	3-55	3-09	3-11	.....	3-43
0-39	0-13	1-09	1-05	1-13	....	1-01	0-59	0-32	0-49	....	0-52	0-07	2-58	2-36	3-01	.....	2-55
0-29	0-14	0-47	1-13	0-52	1-10	0-52	0-39	0-43	0-32	0-20	0-38	0-04	2-13	2-43	2-11	2-17	2-17
0-19	0-15	0-59	0-47	0-55	....	0-56	0-34	0-16	0-41	....	0-32	0-37	2-44	2-14	2-47	.....	2-39
0-27	0-10	0-51	0-52	1-05	....	0-53	0-32	0-45	0-37	....	0-35	0-16	2-16	2-30	2-35	.....	2-21
0-30	0-15	1-01	1-09	1-05	0-45	1-03	0-54	0-37	0-49	0-40	0-49	0-24	3-04	2-55	3-03	2-34	3-01
0-19	0-10	0-42	0-49	0-54	0-45	0-45	0-24	0-26	0-39	0-25	0-27	0-0	1-35	1-44	2-02	1-39	1-41
0-38	0-16	0-48	1-06	1-04	1-23	0-56	0-36	0-34	0-57	1-12	0-41	0-02	2-20	2-36	2-57	3-31	2-33
0-36	0-18	1-04	1-01	1-02	1-15	1-07	0-39	0-43	1-12	0-59	0-50	0-10	2-47	2-48	3-18	3-18	3-01
0-42	0-14	1-06	1-15	1-16	1-18	1-10	0-45	0-40	0-52	0-54	0-47	0-16	3-03	3-07	3-20	3-24	3-09
1-15	*	2-09	2-13	2-21	2-20	2-13	†	....	....	....	....	0-15	3-39	3-43	3-51	3-50	3-43
2-28	*	....	....	....	....	2-18	†	....	....	....	....	0-15	.....	.....	.....	.....	5-01

MARY.

Average No. of cubic yards. per ring.	Time mucking, per cubic yard.	Average Time per Ring.				Unavoidable Delays (Not Included in Average Time per Ring).		
		Shoving and mucking. *	Erection. †	Lost time.	Total.	Items.	Time, hrs.	min.
48.7	0-25	20-33	4-21	0-12	25-06	1st bulkhead	80	00
44.2	0-46	39-44	4-44	1-15	39-43	2d "	156	00
39.0	0-12	8-06	2-23	0-30	10-59	Grouting rock section	280	00
41.6	0-10	7-10	1-59	0-0	9-09	Blow-outs	222	00
42.6	0-10	7-23	2-35	0-05	10-03	Shield repairs	326	40
13.8	0-11	2-29	2-32	0-20	5-21	Horizontal timbers	69	30
3.6	0-06	0-40	2-39	0-14	3-33	Total	1 134	10
17.8	0-14	4-14	2-41	0-16	7-11	Per ring	0	53
10.6	0-4	0-56	1-57	0-16	3-09	.....	.....	
14.1	0-10	2-28	2-18	0-15	5-01	.....	.....	

‡ Excavating ahead of shield. § Shoving shield into silt with.....doors open.

taining No. 1 bore segments, rings containing No. 2 bore segments, and taper rings, and it will be seen that, on the average, taper rings took 22 min. (or 24%) more time to erect and to bolt than ordinary ones, and that rings containing No. 2 bore segments took 14 min. (or 15%) more.

The average time taken for each operation at all the working faces is given in Table 28. The work has been subdivided into the different kinds of ground encountered.

The progress, as shown by the amount of work done each month by each shield, is given in Table 29.

TABLE 28.—Shield-Driven Tunnel Work.—Total Number of tracts Gy-West and Gj, and the Average Size of Gang, Various Operations Involved in Building Tunnel in Also the Extent and Nature of

Weight of iron.	Description of materials.	Total No. of rings.	Total No. of feet.	Total number of 8-hour shifts.	Average air pressure.	Ave. No. of Men in Gang.				
						Shield.	Drilling.	Grouting.	Air Transp't.	Total.
						Unit.	Unit.	Unit.	Unit.	Unit.
Ordinary iron.	Rock	165	412.5	597	16	18	9	0.25	1	28
	Rock and earth and rock and gravel	177	442.5	500	14	22	5	0.3	2	30
	Sand and gravel (unobstructed), N. J.	188	470.0	241	13	24	.....	0.6	3	27
	Sand and silt (with piles)	171	427.5	199	22	23	.....	1.0	3	27
	Silt under R. R. tracks, N.Y.	396	990.0	355	19	27	.....	.....	3	30
	Rip-rap and silt under bulkhead	77	192.5	193	23	26	.....	.....	4	30
	Total mixed and difficult ground	1 174	2 935.0	2 085	17	22	4	0.3	3	29
	Silt—ordinary iron	1 302	3 255.0	676	25	22	.....	.....	4	26
Heavy.	Silt—heavy iron	2 209	5 522.5	791	26	25	.....	.....	8	33
	Silt—ord. and heavy iron under river	3 511	8 777.5	1 467	26	24	.....	.....	6	30
	Grand total	4 685	11 712.5	3 532	21	23	2	0.2	4	29

Average rings built by one shield = 1 146½.

Average time per ring.....

Delays.....

Total time per ring.....

Note.—The "unavoidable delays" included in this table do not embrace the periods observations, shortage of iron due to change of design, and holidays.

K. Including time for jacks.

L. Including time spent by the whole gang on bolting; in addition to this there was

M. Chiefly due to breakdowns of hydraulic lines and erector.

Air Pressure.—The air pressure varied from 17 to 37 lb. Behind the river line it averaged 17 lb. and under the river 26 lb. Behind the river lines the pressure was generally kept about equal to the water head at the crown, except where at Weehawken, as previously described, this was impossible.

In the silt the pressure was much lower than the hydrostatic head at the crown, but if it became necessary to make an excavation ahead of the shield, for example at the junction of the shields, the air pressure required was about equal to the weight of the overlying material, namely, the water and the silt, as the silt, which weighed from

RINGS ERECTED AND SHIFTS WORKED BY ALL FOUR SHIELDS IN CONAMOUNT OF EXCAVATION AND TIME TAKEN PER RING FOR THE EACH OF THE SEVERAL KINDS OF GROUND ENCOUNTERED; ALL THE UNAVOIDABLE DELAYS.

Cu. yd. per ring.	Time per cu. yd.	Average Time per Ring.								Ave. Unavoidable Delay per Working Face.		
		Shoving and mucking.		Erecting.		Lost time.		Total.		Items not included in previous figures.	Time.	
											Ave. unit.	
Unit.	Unit.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.		Hrs.	Min.
		K		L		M						
51	0-27	25	15	3	41	0	02	28	58	1st Bulkhead.....	136	00
45	0-26	19	31	2	55	0	11	22	37	2d "	147	54
39	0-12	7	31	2	24	0	20	10	15	Grouting.....	246	00
43	0-09	6	46	2	24	0	09	9	19	Blow-outs..... ...	91	11
42	0-06	4	09	2	51	0	10	7	10	Miscellaneous.....	220	33
43	0-21	14	47	3	41	1	34	20	02	Total.....	851	38
43	0-18	11	02	2	54	0	16	14	12	.....	.....	
12	0-07	1	20	2	35	0	14	4	09	.....	.....	
12	0-05	0	58	1	44	0	10	2	52	....	.....	
12	0-06	1	09	2	05	0	12	3	26	.....	.....	
20	0-11	3	33	2	15	0	13	6	01	....	.....	

Average delay per ring = 0 hrs. 44 min.

..... 6 hrs. 01 min.

..... 44 min.

..... 6 hrs. 45 min.

during which the work was at complete or partial standstill due to experiments and a small gang which spent its whole time bolting.

TABLE 29.—Monthly Progress of Shield-Driven Tunnel Work.

Month.	North Manhattan.				South Manhattan.				North Weehawken.				South Weehawken.				Average progress per shield, lin. ft. per month.
	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	
	For month.	To date.			For month.	To date.			For month.	To date.			For month.	To date.			
1905. May	26	26	200 + 83.7	63.7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15.9
June	26	52	201 + 49.0	65.3	.....	.....	.....	.....	24	24	260 + 76.6	59.3	12	12	260 + 70.0	30.0	38.6
July	28	80	202 + 19.2	70.2	.....	.....	.....	.....	12	36	260 + 46.6	30.0	15	27	260 + 32.4	37.6	34.4
Aug.	26	106	202 + 84.3	65.1	.....	.....	.....	.....	15	51	260 + 09.1	37.5	16	43	260 + 07.4	25.0	31.9
Sept.	21	127	203 + 36.8	52.5	31	31	200 + 96.4	76.4	1	52	260 + 06.6	2.5	18	61	259 + 47.2	60.2	47.9
Oct.	25	152	203 + 99.4	63.6	45	76	202 + 09.2	112.8	10	62	259 + 81.5	25.1	20	81	258 + 97.2	50.0	62.9
Nov.	31	183	204 + 76.9	77.5	31	107	202 + 86.5	77.3	29	91	259 + 09.0	72.5	39	120	257 + 99.7	97.5	81.2
Dec.	59	242	206 + 24.6	147.7	34	141	203 + 71.8	85.3	46	137	257 + 94.0	115.0	77	197	256 + 07.1	192.6	135.1
1906. Jan.	94	336	208 + 59.8	235.2	27	168	204 + 39.4	67.6	77	214	256 + 01.4	192.6	73	270	254 + 34.6	182.5	169.4
Feb	78	414	210 + 54.9	195.1	64	232	205 + 99.6	160.2	133	347	252 + 68.6	332.8	165	435	250 + 11.7	412.9	275.2
Mar.	56	470	211 + 95.2	140.3	96	328	208 + 39.9	240.3	142	489	249 + 13.3	355.3	111	546	247 + 34 0	277.7	253.4
April.	119	589	214 + 93.0	297.8	84	412	210 + 59.1	210.2	32	521	248 + 33.3	80.0	78	624	245 + 38.9	195.1	195.7
May	129	718	218 + 15.7	322.7	70	482	212 + 25.3	165.2	121	642	245 + 30.6	302.7	2	626	245 + 33.9	5.0	198.9
June	218	936	223 + 60.9	545.2	140	622	215 + 75.5	350.2	162	804	241 + 25.3	405.3	157	783	241 + 41.1	392.8	423.4
July	155	1 091	227 + 48.5	387.6	82	704	217 + 80.7	205.2	113	917	238 + 42.4	282.9	118	901	238 + 45.9	295.2	292.7
Aug.	145	1 236	231 + 11.2	362.7	134	838	221 + 15.8	335.1	138	1 055	234 + 97.1	345.3	140	1 041	234 + 95.8	350.1	348.3
Sept.	89	1 325	233 + 34.1	222.9	168	1 006	225 + 35.8	420.0	55	1 110	233 + 59.5	137.6	177	1 218	230 + 52.8	443.0	305.9
Oct.	.....	.....	.....	.....	105	1 111	227 + 98.6	262.8	1	1 111	233 + 57.0	2.5	94	1 312	228 + 16.8	236.0	125.3
Nov.	.....	.....	.....	.....	7	1 118	228 + 16.8	18.2	9	1 120	233 + 34.1	22.9	.....	.....	.....	.....	10.3

97 to 106 lb. per cu. ft. and averaged 100 lb. per cu. ft., acted like a fluid.

A ½-in. air line was taken direct from the working chamber to the recording gauges in the engine-room, which enabled the engine-room force to keep a constant watch on the air conditions below. To avoid undue rise of pressure, a safety valve was set on the air line at each lock, set to blow off if the air pressure rose above that desired. The compressor plant was ample, except, as before described, when passing the gravel section at Weehawken.

Records were kept of the air supply, and it may be said here that the quantity of free air per man per hour was in general between 1 500 and 5 000 cu. ft., though in the open gravel where the escape was great it was for a time as much as 10 000 cu. ft. For more than half the silt period it was kept between 3 000 and 4 000 cu. ft., but when it seemed proved beyond doubt that any quantity more than 2 000 cu. ft. had no beneficial effect on health, no attempt was made to deliver more, and on two separate occasions for two consecutive weeks it ran as low as 1 000 cu. ft. without any increase in the number of cases of bends.

The amount of CO_2 in the air was also measured daily, as the specifications called for not more than 1 part of CO_2 per 1 000 parts of air. The average ranged between 0.8 and 1.5 parts per 1 000, though in exceptional cases it fell as low as 0.3 and rose to 4.0. The air temperature in the tunnels usually ranged from 55° to 60° Fahr., which was the temperature also of the surrounding silt, though at times, in the earlier parts of the work when grouting extensively in long sections of the tunnel in rock, it varied from 85° to 110° Fahr.

Grouting.—Grout of one part of Portland cement to one part of sand by volume was forced outside the tunnel lining by air pressure through 1½-in. tapped and plugged grout holes formed in each segment for this purpose, wherever the ground was not likely to squeeze in upon the metal lining as soon as this was erected. That is to say, it was used everywhere up to the river line; between river lines it was not used except at the New York bulkhead wall in order to fill voids in the rip-rap, and at the point of junction of the shields where the space between the metal lining and the shield skins outside it was grouted. Cow Bay sand was used, and it had to be screened to remove particles greater than $\frac{1}{10}$ in. in diameter, which would choke the valves.

For later grouting work, namely, in the top of the concrete lining inside the metal lining, Rockaway Beach sand was used. This is very fine, and did not need screening; it cost more, but the saving of screening and the non-blocking of valves, etc., resulted in a saving.

The grout was mixed in a machine shown in Fig. 2, Plate XLI, which is a view of the grouting operation.

The grout pipes were not screwed directly into the tapped hole in the segments, but a pipe containing a nipple and valve was screwed into the grout hole and the grout pipe screwed to the pipe. This prevented the waste of grout, enabled the valve to be closed and the grout pipe disconnected, and the pipe to be left in position until the grout had set. In the full rock section, 20 or 30 rings were put in without grouting; then the shield was stopped, the last two or three rings were detached and pulled ahead by the shield, a masonry stop-wall was built around the outside of the last ring left in, and the whole 20 or 30 rings were grouted at one time. In the landward silt and gravel each ring had to be grouted as soon as the shield had left it, in order to avoid the flattening caused by the weight coming on the crown while the sides were as yet unsupported. The grout was prevented from reaching the tail of the shield by plugging up the space with empty cement bags, assisted by segmental boards held against the face of the leading ring by U-shaped clamps, fitting over the front circumferential flange of the ring and the boards, and tightened by wedges. The air pressure varied between 70 and 100 lb. per sq. in. above normal.

The force consisted of one pipe-fitter and one or two laborers employed part of their time. When a considerable length was being grouted at a time, as in the full rock section, many laborers were employed for a short period.

Transportation and Disposal.

The transportation and disposal will be described under the following headings:

Receipt and Unloading of Materials,
Surface Transportation,
Tunnel Transportation,
Disposal.

Receipt and Unloading of Materials.—At the Manhattan Shaft the contractor laid a spur siding into the yard from the freight tracks of the New York Central Railroad, which immediately adjoins the yard on the west. There was also wharfage on the river front about 1 500 ft. away.

At the Weehawken Shaft there were four sidings from the Erie Railroad and one from the West Shore Railroad. Access to the river was gained by a trestle direct from the yard, and Baldwin Avenue adjoined the yard.

All the iron lining arrived by railroad. It was unloaded by derricks, and stacked so that it was convenient for use in the tunnel. The Manhattan derricks were a pair of steel ones with 39-ft. booms, worked by a 30-h.p., 250-volt, electric motor. There was also a stiff-leg derrick with 50-ft. boom, on a platform near the shaft, which was worked by a 40-h.p., 250-volt motor. At Weehawken there were two 45-ft. boom, stiff-leg derricks of 2 tons capacity, one worked by a 42-h.p. Lidgerwood boiler and engine, and the other by a 25-h.p., 250-volt, electric motor. These derricks were set on elevated trestles near the Erie Railroad sidings. There was a 50-ft. stiff-leg derrick with a 70-h.p. Lidgerwood boiler and engine near the cement warehouse on the West Shore Railroad.

The storage area for iron lining was 1 800 sq. ft. at Manhattan and 63 000 sq. ft. at Weehawken; the maximum quantity of lining in storage at any one time was 150 rings at Manhattan and 1 200 rings at Weehawken.

The cement, which was issued and sold by the Company to the contractor, was kept in cement warehouses; that at the New York side was at Eleventh Avenue and 38th Street, or some 1 200 ft. from the shaft, to which it was brought by team; that at Weehawken was adjacent to the shaft, with a 2-ft. gauge track throughout it and directly connected with the shaft elevator.

Surface Transportation.—In the early days the excavation was handled in scale-boxes of 1 cu. yd. capacity which were hoisted up the shafts by a derrick, but, when the iron period began, two-cage elevators were put in at each shaft. They were worked by a single, friction-drum, Lidgerwood, steam hoisting engine of 40 h.p.

All materials of construction were loaded on cars on the surface at the point where they were stored, and hauled on these to the ele-

vators, sent down the shaft, and taken along the tunnels to the desired point without unloading.

The narrow-gauge railway on the surface and in the tunnel was of 2-ft. gauge with 20-lb. rails. About 70 flat cars and 50 mining cars were used at each shaft. On the surface at Manhattan these were moved by hand, but at Weehawken, where distances were greater, two electric locomotives on the overhead trolley system were used.

Tunnel Transportation.—The mining cars shown in Fig. 19 were of 1¼ cu. yd. capacity. The short wheel base and unbalanced loading caused a good many upsets, but they were compact, easily handled, and could be dumped from either side or end.

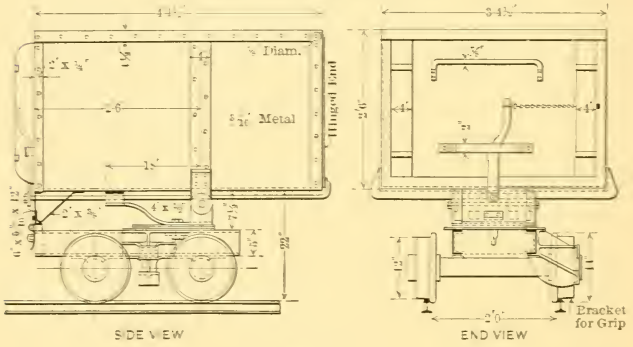


Fig. 19.

The flat cars shown in Fig. 20 were of 3 tons capacity, and could hold two tunnel segments. As the working face was down grade from the shafts, the in-bound cars were run by gravity. For out-bound cars a cable haulage system was used, consisting of double-cylinder, Lidgerwood, single friction-drum, hoisting engines (No. 32) of 6 h.p., with cylinders 5 in. in diameter and 6 in. stroke and drums 10 in. in diameter. These were handily moved from point to point, but, as there was no tail rope, several men had to be used to pull the cable back to the face. After the second air-lock bulkhead walls had been built, a continuous-cable system, worked electrically, was put in each tunnel between the first and second air-locks.

The engine consisted of an electric motor driving a 3-ft. 6-in. drum hoist around which a $\frac{3}{4}$-in. steel wire cable passed three times. The cable was led around a sheave, down the tunnel on the right side of the in-bound track, and returned on the left side of the out-bound track. It was then carried around a set of sheaves, where a tension

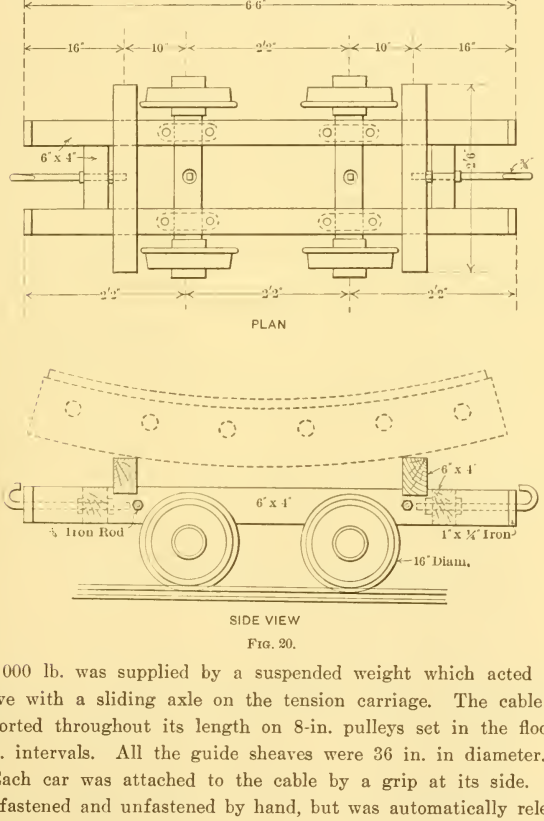


Fig. 20.

of 1 000 lb. was supplied by a suspended weight which acted on a sheave with a sliding axle on the tension carriage. The cable was supported throughout its length on 8-in. pulleys set in the floor at 50-ft. intervals. All the guide sheaves were 36 in. in diameter.

Each car was attached to the cable by a grip at its side. This was fastened and unfastened by hand, but was automatically released just before reaching the turn in the cable near each lock. This

system could haul without difficulty an unbalanced load of 10 muck cars, spaced 100 ft. apart, up a 2% grade. The cable operated over about 1 000 ft. of tunnel, the motor being placed at the top of the grade. The driving motor was of the semi-armored, 8-pole, series-wound type, rated at 25 h.p., 635 rev. per min., and using direct current at 220 volts. The speed of handling the cars was limited by their having to pass through the air-locks on a single track. As many as 106 cars have been hauled each way in one 8-hour shift.

Disposal.—At Manhattan the tunnel muck was carried from the elevator over the upper level of the yard trestle and dumped into bins on the 33d Street side, whence it was teamed to the public dump at 30th Street and North River. At Weehawken the rock excavation was removed by the Erie Railroad on flat cars on which it was dumped by the tunnel contractor, but all the silt muck was teamed away to some marshy ground where dumping privileges were obtained.

The typical forces employed on transportation were as follows:

Receipt and Unloading of Material: Surface Transportation and Disposal.

At Manhattan Shaft, on 10-hour shifts:

2 Engineers on derricks	@	$3.00	per day.
2 Foremen	"	3.25	" "
15 Laborers loading and unloading iron.	"	1.75	" "
7 Laborers on disposal	"	1.75	" "
6 Teams	"	7.50	" "

At Weehawken Shaft, on 10-hour shifts:

3 Engineers on derricks and locomotives	@	$3.00	per day.
16 Laborers loading and unloading iron.	"	1.75	" "
3 Foremen	"	3.50	" "
11 Laborers on disposal	"	1.75	" "
6 Teams on disposal	"	6.50	" "

Tunnel Transportation (Including Shaft Elevator):

Shaft elevators and to and from the first air-lock on 10-hour shift:

2 Engineers	@	$3.00	per day.
2 Signalmen	"	2.00	" "
1 Foreman	"	3.00	" "
12 Laborers	"	1.75	" "

Between first lock and working face, on 8-hour shifts, the force varied:

From 1 to 3 (average 2) Hoist engineers	@	$3.00	per day.
From 0 to 2 (average 1) Lockman	"	2.75	" "
From 1 to 2 (average 2) Trackmen	"	3.00	" "
From 2 to 7 (average 4) Cablemen (pulling back cable)	"	3.00	" "

Pumping.—The water was taken out of the invert by a 4-in. blow-pipe which was always kept up to a point near the shield and discharged into the sump near the shaft.

When the air pressure was removed and the blow-pipe device, consequently, was unavailable, small Cameron pumps, driven by compressed air, and having a capacity of about 140 gal. per hour, were used, one being set up wherever it was necessary to keep the invert dry; for example, at points where caulking was in progress.

Lighting.—The tunnels were lighted by electricity, the current being supplied, at a pressure of 250 volts, from the dynamos in the contractor's power-house.

Two 0000 wire cables were used as far as the second air-locks, about 1 650 ft. from the power-house, on each side; and beyond that point, to the junction of the shields (about 1 750 ft.), 00 and 0 wires were used. These cables also carried the current for the cable haulage system. Two rows of 16-c.p. lamps, provided with reflectors, were used in each tunnel; one row was along the side just above the axis, with the lights at about 30-ft. intervals; the other along the crown, with the lamps halfway between the side lamps, also at 30-ft. intervals. At points where work was in progress three groups of 5 lights each were used. The tunnels as a whole were well lighted, and in consequence work of all kinds was much helped.

Period No. 2.—Caulking and Grummeting.—November, 1906, to June, 1907.—After the metal lining had been built completely across the river in both tunnels, the work of making it water-tight was taken up. This consisted in caulking into the joints between the plates a mixture of sal-ammoniac and iron borings which set up into a hard rusty mass, and in taking out each bolt and placing around the shank under the washer at each end a grummet made of yarn

soaked in red lead. These grummets were made by the contractor on the works, and consisted of three or four strands of twisted hemp yarn, known as "lath yarn," making up a rope-like cross-section about ¾ in. in diameter. Usually, one of these under each washer was enough, but in wet gravel, or where bolts were obliquely in the bolt-holes, two were used at each end. After pulling the grummets in, all the nuts were pulled up tight by wrenches about 3 ft. long, with two men on one wrench. Bolts were not passed as tight unless the nut resisted the weight of an average man on a 2½-ft. wrench.

Before putting in the caulking mixture, the joints were carefully scraped out with a special tool, cleaned with cotton waste, and washed with a stream of water. The usual mixture for sides and invert was about 2 lb. of sal-ammoniac and 1 lb. of sulphur to 250 lb. of iron filings or borings. In the arch, 4 lb. of sal-ammoniac and 3 lb. of sulphur to 125 lb. of filings was the mixture. A small hand-hammer was used to drive the caulking tool, but, in the sides and invert, air hammers were used with some advantage. The success of work of this kind depends entirely on the thoroughness with which the mixture is hammered in; and the inspection, which was of an exceedingly monotonous nature, called for the greatest care and watchfulness on the part of the Company's forces, especially in the pocket iron, where each bolt had to be removed, the caulking done at the bottom of the pockets put in, the bolts replaced, and the rest of the pockets filled. The results have been satisfactory, as the leakage under normal air and prior to placing the concrete averaged about 0.14 gal. per lin. ft. of tunnel per 24 hours, which is about 0.0035 gal. per lin. ft. of joint per 24 hours. With each linear foot of joint is included the leakage from 1.27 bolts. Afterward, when the concrete lining was in, the leakage was found to be about 0.05 to 0.06 gal. per lin. ft. of tunnel per 24 hours, which compares favorably with the records of other lined tunnels. The typical gang employed on this work was as follows:

In Pocket Iron:

1 General foreman	@	$5.00	per day.
1 Mixer	"	3.00	" "
1 Nipper	"	3.00	" "
5 Caulkers	"	3.00	" "
10 Grummeters	"	3.00	" "

In Pocketless Iron:

1 General foreman	@	$5.00	per day.
1 Mixer	"	3.00	" "
1 Nipper	"	3.00	" "
3 Caulkers	"	3.00	" "
12 Grummeters	"	3.00	" "

The average amount of caulking and grummeting done per shift with such a gang was (with pocketless grooves), 348 lin. ft. of joint and 445 bolts grummeted; and in pocket iron: 126 lin. ft. of joint and 160 bolts grummeted.

The caulking and grummeting work was finished in June, 1907, this completing the second period.

Period No. 3.—Experiments, Tests, and Observations.—April, 1907, to April, 1908.—The third period, that of tests and observations in connection with the question of foundations, is dealt with in another paper. It occupied from April, 1907, to November, 1908. The results of the information then gathered was that it was not thought advisable to go on with the foundations.

Period No. 4.—Capping Pile Bores, Sinking Sumps, and Building Cross-Passages.—April, 1908, to November, 1908.—In order to reduce the leakage from the bore segments to the least possible amount before placing the concrete lining, it was decided to remove the plugs and replace them with flat cover-plates; these have been described before, together with the filling of Bore Segments No. 2 with mortar to reduce the leakage around the distance piece.

During this period the turnbuckles to reinforce the broken plates were put in, and the sump sunk at the lowest point of the tunnel. These sumps have been described in a previous part of this paper; they were put down without trouble. As much as possible of the concrete lining was put in before the lining castings were taken into the tunnel, as the space inside was very restricted. The first lining casting was bolted to the flat flanges of the sump segment, the bolts holding the latter to the adjacent segments were removed, and the whole was forced down with two of the old shield jacks, taking a bearing on the tunnel. The two together exerted a pressure of about 150 tons. The plugs in the bottom of the sump segment were taken out, and pipes were put in, through which the silt squeezed up into the tunnel and relieved the pressure on the sump segment.

If the silt did not flow freely, a water-jet was used. The sump was kept plumb by regulating the jacks. In this way the sump was sunk, adding lining sections one by one, and finally putting on the top segment, which was composed of three pieces.

The time taken to sink one sump was about 4 days, working one 8-hour shift per day, and not counting the time taken to set up the jacks and bracing. The sinking of each section took from 4 to 6 hours. The air pressure was 25 lb. and the hydrostatic head 41 lb. per sq. in. The force was 1 assistant superintendent at $6.00 per day, 1 foreman at $4.50, and 6 laborers at $3.00 per day.

Cross-Passages.—It was during this period that the five cross-passages previously mentioned were built. In the case of those in the rock, careful excavation was needed so as to avoid breaking the iron lining. Drilling was done from both ends, the holes were closely spaced, and about 2 ft. 6 in. deep, and light charges of powder were used. The heading, 5 by 7 ft. in cross-section, was thus excavated in five lengths, with 24 holes to a length, and about 23 lin. ft. of hole per yard. About 5.3 lb. of powder per cu. yd. was used. The sides, top, and bottom were then drilled at a very sharp angle to the face and the excavation was trimmed to the right size. This widening out took about $7\frac{1}{2}$ ft. of hole per cu. yd., and 0.9 lb. of powder.

In the passages in silt the excavation had to be 12 ft. wide and 13 ft. 8 in. high to give enough room inside the timbers. The plates at one end of the passage were first removed. An air pressure of 17 lb. was carried, which was enough to keep the silt from squeezing in and yet left it soft enough to be chopped with a spade.

A top heading, of full width and 6 ft. 8 in. high, was first taken out, and the roof was sheathed with 2-in. boards held by 10 by 10-in. head trees at 3-ft. centers, with 10 by 10-in. side trees. The lower 7 ft. of bench was then taken out, a tight floor of 6 by 6-in. cross-timber was put in, and also longer side trees, the head trees being temporarily held by two longitudinal 10 by 10-in. stringers blocked in place. The bulk of the space between the side trees was filled with 10 by 10-in. posts and blocking. The plates at the other end of the passage were then taken out from the other tunnel.

After the excavation was out, the outer reinforced concrete lining was built. Rough forms were used, as the interior surfaces of the passages were to be rendered with a water-proofing cement. A few

grout pipes were built in, and all voids outside the concrete were grouted. Grouting was also done through the regular grout holes of the metal lining around the openings.

In the case of the most westerly of the cross-passages at Weehawken, which was in badly seamed rock carrying much water, a steel interlining, rather smaller than the concrete, was put in. The space between the concrete and the steel was left open, so that water coming through the concrete lining was stopped by the steel plate. This water was led back to the shield chamber in a special drain laid in the bench of the river tunnel and behind the ducts. From the shield chamber the water ran with the rest of the drainage from the Weehawken Land Tunnels to the Weehawken Shaft sump.

TYPICAL CROSS-SECTIONS SHOWING SUCCESSIVE STAGES IN PLACING CONCRETE IN RIVER TUNNELS

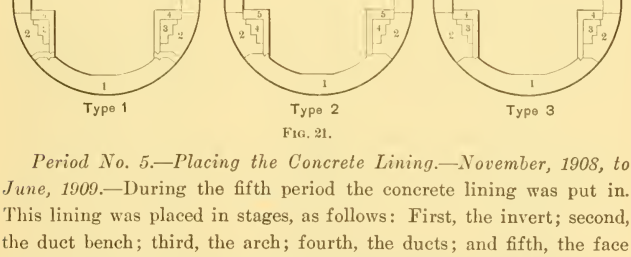


FIG. 21.

Period No. 5.—Placing the Concrete Lining.—November, 1908, to June, 1909.—During the fifth period the concrete lining was put in. This lining was placed in stages, as follows: First, the invert; second, the duct bench; third, the arch; fourth, the ducts; and fifth, the face of the bench. This division can be seen by reference to Fig. 21.

All the work was started on the landward ends and carried toward the middle of the river from both sides. Except where the Weehawken force passed the lowest point of the tunnel, which is at Station 241 or nearly 900 ft. to the west of the middle of the river, all the work was down grade.

Before any concrete was placed, the surface of the iron was cleaned with scrapers and wire brushes, and washed with water. Any leaks in the caulking and grummeting (finished by June, 1907, and therefore all more than 12 months old) were repaired. All the grout hole plugs were examined, and the plugs in any leaking ones were taken out,

smeared with red lead, and replaced. The leakage in the caulking was due to the fact that the tunnel had been settling slightly during the whole 12 months of pile tests, and, therefore, had opened some of the joints. After the caulking had been repaired and the surface thoroughly cleaned, the flanges were covered with neat cement (put on dry or poured on in the form of thick grout) just before the concrete was placed.

Invert Concrete.—The form used for the landward type of concrete, that is, the one with a middle drain, consisted of a frame made of a pair of trussed steel rails on each side of the tunnel and connected at intervals with 6 by 6-in. cross-timbers; two "wing forms" were hung from this frame by adjustable arms. These wings formed the curved sides of the invert, the lip, and the form for the middle drain. The whole form was supported on three wheels, two on the rear end running on a rail laid on the finished concrete, and the third in front attached to the frame by a carriage and running on a rail temporarily laid on the iron lining. The form was braced from the iron lining by 6 by 6-in. blocks.

For the soft-ground type of invert, namely, the one without the middle drain, a form of the same general type was used, except that the form for the middle drain was removed. After the form had been in use for some time, "key pieces" (made of strips of wood about 1 ft. 3 in. in length and 3 by 3 in. in cross-section) were nailed circumferentially on the under side of the wings at 2-ft. intervals. This was done because, at the time, it was not known whether ballasted tracks or some form of rigid concrete track construction would be adopted, and, if the latter, it was desirable not to have the surface smooth.

The concrete was received in cars at the rear end of the form and dumped on a temporary platform. It was then loaded into wheelbarrows on the runways, as shown in Fig. 22. The concrete was thrown from the barrows into the invert, where it was spaded and tamped.

In cases where there was steel-rod reinforcement, the concrete was first brought up to the level of the underside of these rods, which came between the wings; the rods were laid in place, and then more concrete was placed over the rods and brought up to the level of the bottom of the wings. Where there was no reinforcement, the concrete was brought up in one lift.

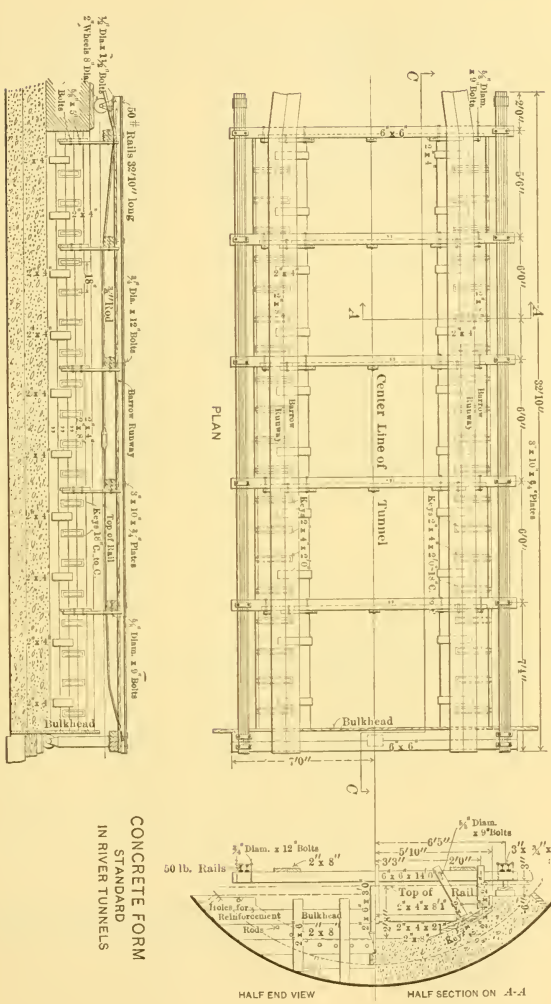


FIG. 22.

CONCRETE FORM STANDARD IN RIVER TUNNELS

After this was finished, the concrete behind the wings was placed, thoroughly spaded and tamped, and, where there were longitudinal reinforcing rods, these were put in at their proper level. Where there were circumferential rods, the 16-ft. rods had already been put in when the lower part of the concrete was placed. As the invert was being finished off, the 8-ft. rods were embedded and tied in position.

The longitudinal rods were held in place at the leading end of each length of arch by the wooden bulkhead, through which holes were drilled in the proper position. At the rear end they were tied to the rods projecting from the previous length. The quantity of water used in mixing the invert concrete needed very nice adjustment; if too wet, the middle would bulge and rise when the weight of the sides came on it; and, if too dry, it would not pack properly between the flanges of the iron lining. The difficulties as to this were often increased by the flow of accumulated leakage water from the tunnel behind on the concrete while it was being put in. To prevent this, a temporary dam of sand bags was always built across the last length of finished invert concrete before beginning a new length. A sump hole, about 4 by 4 ft. and 1 ft. deep, was left every 800 ft. along the tunnel, and a small Cameron pump was put there to pump out the water.

The invert forms were left in place about 12 hours after the length was finished. The average time taken to fill a length of 30 ft. was 7 hours, the form was then left 12 hours, and it took 2 hours to set it up anew. The total time for one length, therefore, was 21 hours, equal to 34 ft. per 24 hours. At one place, a 45-ft. form was used, and this gave an average speed of 45 ft. per 24 hours.

An attempt was made to build the invert concrete without forms (seeing that a rough finish was desired, as previously explained, to form a key for possible sub-track concrete), but it proved a failure.

The typical working force (excluding transport) was as follows:

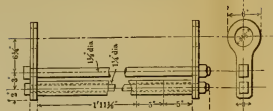
1 Foreman	@	$3.25	per shift.
2 Spaders	"	2.00	" "
9 Laborers	"	1.75	" "

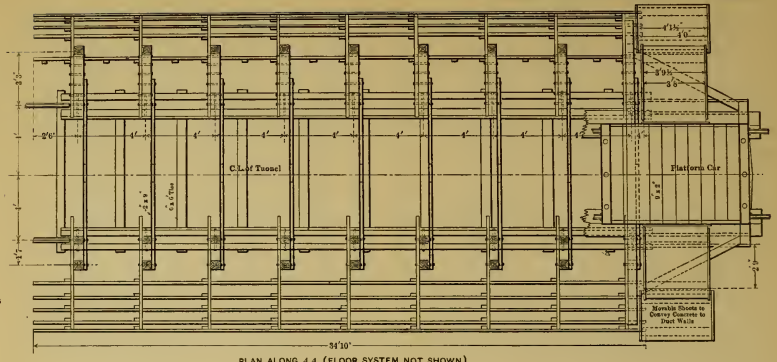
The average time taken to lay a 30-ft. length of invert was 7 hours; the two spaders remained one hour extra, smoothing off the surface.

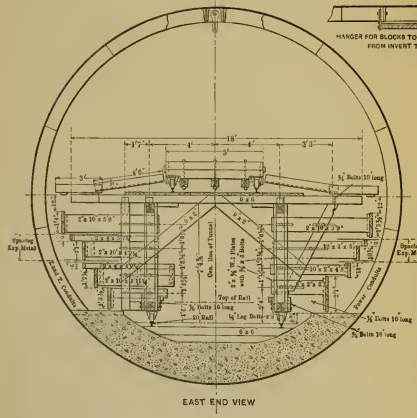
For setting the form, the force was:

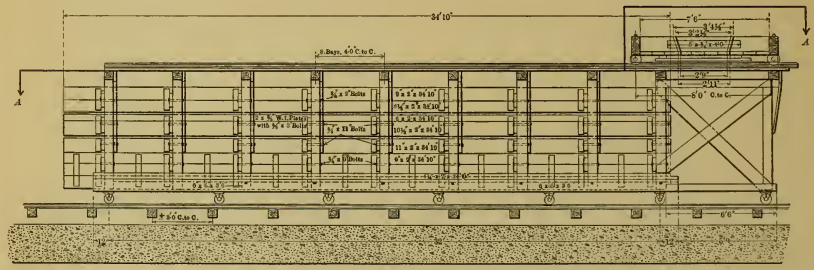
1 Foreman	@	$4.50	per shift.
5 Carpenters	"	3.25	" "
6 Carpenters' helpers	"	2.25	" "

DUCT-BENCH CONCRETE FORM IN RIVER TUNNELS









The average time taken to erect a form was 2 hours, 1 carpenter and 1 helper remaining until the concrete was finished.

Duct Bench Concrete.—The duct bench (as described previously) is the portion of the concrete on which the ducts are laid. The exact height of the steps was found by trial, so as to bring the top of the ducts into the proper position with regard to the top and the face of the bench.

Both kinds of duct bench forms were of the same general type. A drawing of one of them is shown on Plate XLII. The form consisted of a skeleton framework running on wheels on a track at the level of the temporary transportation tracks. The vertical faces of the steps were formed by boards supported from the uprights by adjustable arms. The horizontal surfaces were formed by leveling off the concrete with a shovel at the top of the vertical boards. Where the sheets of expanded metal used for bonding came at a step, the lower edge of the boards forming the back of the step was placed 1 in. above the one forming the front of it; but, when the expanded metal came in the middle of a step, a slot 1 in. wide was left at that point to accommodate it.

A platform was formed on the top of the framework for the form, and on this a car forming a sort of traveling stage was run. There was ample room to maintain traffic on a single track through the form. A photograph of the form is shown in Fig. 1, Plate XLIII.

The concrete, for the most part, was received at the form in $\frac{3}{4}$-cu. yd. dumping buckets. The buckets were lifted by the rope from a small hoisting engine. This rope passed over a pulley attached to the crown of the tunnel and dumped into the traveling stage on the top of the form. In this the concrete was moved along to the point where it was to be deposited, and there it was thrown out by shovels into the form below. For a portion of the period, while the duct bench concrete was being laid, it was not necessary to maintain a track for traffic through the form and, during that period, the concrete for the lower step was placed from below the form, the concrete being first dumped on a temporary stage at the lower track level.

Owing to the horizontal faces of the steps being uncovered, there was a tendency for the concrete there to rise when concrete was placed in the steps above. For this part of the work, also, it was necessary to see that the concrete was not mixed too wet, for, when that was the case, the concrete in the upper steps was very apt to flow out at the

top of the lower one. At the same time, there was the standing objection to the mixture being too dry, namely, the responsibility of getting a sufficient amount of spading and tamping done. Particulars of the exact quantity of water used are given later in describing "Mixing." Fig. 2, Plate XLIII, illustrates the process of laying.

In the section of the tunnel in which there were circumferential reinforcement rods in the duct bench, the rods were in place before the laying commenced, as they had been placed with the invert concrete. The circumferential reinforcing rods in the arch came down into the upper part of the duct bench concrete; these rods were put in position and tied to the iron lining in the crown at the same time as the duct bench concrete was being finished off. Openings for the manholes were left in the duct bench at the regular stationing.

The average time taken to fill a length of 35 ft. was about 6 hours; the form was then left in position for about 8 hours—usually enough to let the concrete set properly—and then moved ahead; it then took about 3 hours to set it up again ready to continue work. The total time for a length, therefore, was about 17 hours, equal to an average progress of about 49 ft. per day. The average force engaged in duct bench concrete (not including transport) was:

1 Foreman	@	$3.25	per day.
2 Spaders	"	2.00	" "
9 Laborers	"	1.75	" "

Arch Concrete.—By far the greater part of the arch work was put in with traveling centers before the face of the bench was built, in which case the whole of the arch was built at once. A short length of arch at each end of the tunnel was built after the face of the bench, in which case the haunches or lower 5 ft. were laid first and the upper part of the arch later.

The first traveling centers were used on the New York side, and were 50 ft. long. The laggings were of 4-in. yellow pine, built up in panels 10 ft. long and 16 in. wide for the sides, and solely longitudinal lagging 5 ft. long for the key.

It was pretty certain that the results to be obtained from forms of such a length would not be satisfactory, and this was pointed out to the contractor, who, however, obtained permission to use them on trial. Grout pipes were built in, as it was not likely that the concrete could be packed tightly into the upper part of the lining.

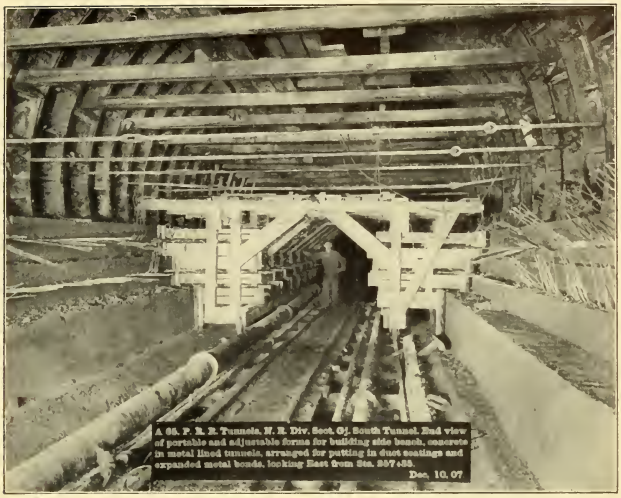

A 98. P. R. R. Tunnels, N. R. Div. Sect. 6. South Tunnel. End view of portable and adjustable forms for building side bench, concrete in metal lined tunnels, arranged for putting in duct coatings and expanded metal bonds, looking East from Sta. 207+85.
Dec. 10, 07

FIG. 1.

A 104. P. R. R. Tunnels, N. R. Div. Sect. G. West. (South Tunnel Manhattan.) Steel rod reinforcement (Type C. Drawing K 1097.) Also showing laying of duct bench concrete, looking West from Sta. 210+35.
Nov. 6, 08.

FIG. 2.

After about 300 lin. ft. of arch had been built with these forms, a test hole was cut out and large voids were found, and, to confirm this, another hole was cut, and similar conditions observed.

The results were so unsatisfactory that orders were given that the use of longitudinal key lagging should be discontinued, and cross or block lagging used instead. These block laggings were 6 in. in length (in the direction of the tunnel) and 2 ft. in width; at the same time, the system of grout pipes was changed. This will be described later under "Grouting." It was soon found that with block lagging a better job could be made of packing the concrete up into the keys, but the time taken to "key up" a 50-ft. length was so great that the rest of the arch had set by the time the key was finished. Despite a lot of practice, this was the case, even in the unreinforced type. When the reinforcing rods were met, the time for keying up became still greater, and therefore the contractor was directed to shorten the forms to 20-ft. lengths. A typical working force for a 50-ft. length was:

1 Foreman	@	$3.25	per day.
4 Spaders	"	2.00	" "
12 Laborers	"	1.75	" "

Details of the 20-ft. forms are shown on Plate XLIV. The lower 4 ft. of lagging was built on swinging arms, which could be loosened to allow the centers to be dropped and moved ahead. The rest of the lagging was built up in panels 10 ft. long and 1 ft. 4 in. high. The ribs rested on a longitudinal timber on each side; these were blocked up from the top step of the duct bench concrete. When the form was set, or when it was released, it was moved ahead on rollers placed under it.

The concrete was received at the form in ¾-cu. yd. dumping buckets; from the flat cars on which they were run, these were hoisted to the level of the lower platform of the arch form. At this level the concrete was dumped on a traveling car or stage, and moved in that to the point on the form where it was to be placed. For the lower part of the arch, the concrete was thrown directly into the form from this traveling stage, but, for the upper part, it was first thrown on the upper platform of the arch. The hoisting was done by a small Lidgerwood compressed-air hoister, and set up on an overhead platform across the tunnel. The pulley over which the cable from the hoister passed was attached to the iron lining near one end of the form, and the traveling stage ran back

from the arch form on a trailer, shown on Plate XLIV. When it was impossible to hang a pulley—owing to the concrete arch having been built at the point where the trailer stood—an **A**-frame was built on the trailer, and the pulley was attached to that.

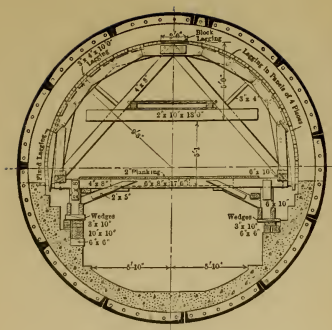
In laying the lower part of the arch, about 1 ft. of lagging (including the swinging arms) was first set, the other panels being pulled up toward the top of the arch. When that was filled, the next panel above was lowered into place, and the work continued. As the concrete rose toward the key, it was packed up to a radial surface, so that the arch would not be unduly weakened if the sides set before the key was placed. All the time, great care was taken to see that the concrete was carefully packed into the segments of the metal lining. The quantity of water used in the concrete was carefully regulated, more being used in the lower than in the upper parts of the arch.

In places where there were no reinforcing rods, the width of the concrete key was the length of the block lagging, namely, 2 ft. Where there was circumferential reinforcement, the key had to be more than 5 ft. wide, in order to take the 5-ft. closure rods used in the key. This naturally increased the time of keying very much. On the places where the 5-ft. longitudinal laggings were used, it was impossible to fill the flanges of the metal lining much higher than their undersides.

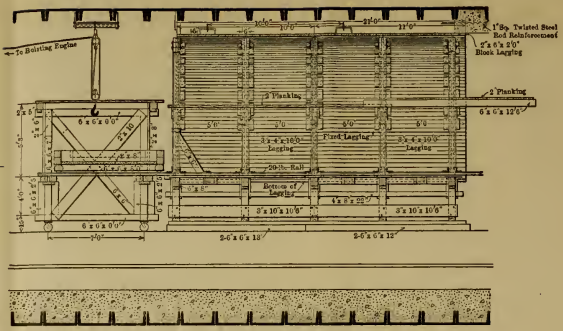
As the concrete used in the key had to be much drier than that used elsewhere, it was not easy to get a good surface. This trouble was overcome by putting a thin layer of mortar on the laggings just before the concrete was put in.

The overhead conductor pockets were a great hindrance to the placing of the key concrete, especially where the iron was below true grade. Whenever an especially troublesome one was met, a special grout pipe was put in to fill up unavoidable holes by grouting after the concrete had set. All the circumferential reinforcing rods were bent in the tunnel by bending them around a curved form of less diameter than the required bend. This generally left them all right in the middle of their length, but with their end portions too straight; in such cases the ends were bent again. All rods were compared with a template before being passed for use.

The arch forms were left up for 48 hours after keying was finished. Levels taken after striking the forms showed that no appreciable settlement occurred. An average gang for a 20-ft. length of arch was:



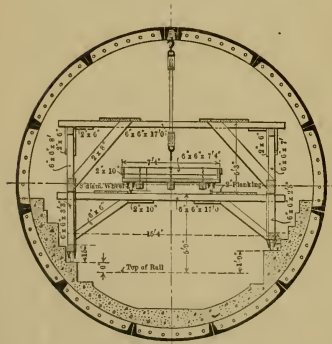
END VIEW OF ARCH FORM
LOOKING WEST



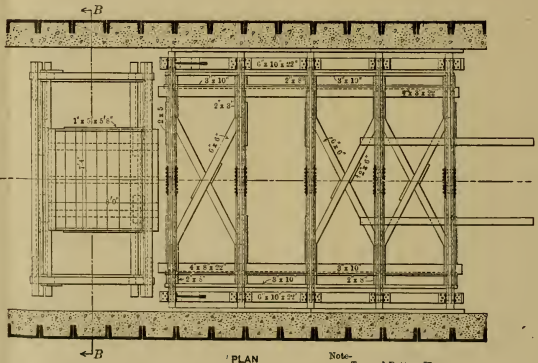
LONGITUDINAL SECTION ON CENTER LINE
LOOKING NORTH

CROSS-SECTION

LONGITUDINAL SECTION



SECTION B-B



PLAN

Note—Top and Bottom Floors not shown

DETAILS OF 20-FOOT MOVABLE FORM AND TRAVELER

1 Foreman	@	$3.25	per shift.
2 Spaders	"	2.00	" "
10 Laborers	"	1.75	" "

Table 30 shows the progress attained under various conditions.

Whenever the face of the bench concrete was constructed before the arch, the latter was built in two separate portions, that is, the bottom 5 ft., or "haunches" of the arch, as they were termed, were built on each side and the rest of the arch later. This involved the use of two separate sets of forms, namely, for the haunch and for the arch. Not very much arch was built in this way, and, as the methods were in principle precisely the same as those used when all the arch was built in one operation, no detailed description is needed.

No provision was made in the contract for grouting the concrete arch, but it soon became evident that by ordinary methods the top part of the concrete could not be packed solid against the iron segments, especially in the keys. As it was imperative to have the arch perfectly solid, it was determined to fill these unavoidable gaps with a 1:1 Portland cement grout, at the same time making every effort to reduce the spaces to a minimum. This made it necessary to build grout pipes into the concrete as it was put in.

The first type of grout pipe arrangement is shown as Type *A*, in Fig. 23. This was used with the longitudinal key laggings; when this method was found to be no good, and cross-laggings were used, the system shown as Type *B*, in Fig. 23, was adopted, in which vents were provided to let out the air during grouting. The expense of these pipes was high, and the contractor obtained permission to use sheet-iron tubes, which, however, were found to be unsuitable, so that the screwed pipes were used again. The contractor next obtained permission to try dispensing altogether with the vent pipes, and so Type *C*, in Fig. 23 was evolved. This, of course, was found to be worse than any of the other systems, as the imprisoned air made it impossible to force grout in. Several other modifications were made, and are shown in Fig. 23.

It was then decided to devise as perfect a system as possible, without allowing the question of cost to be the ruling factor, and to use that system throughout. In this system, shown as Type *S*, in Fig. 23, most of the vent pipes were contained in the concrete, and their size was independent of the thickness of the arch, so that they were easily

TABLE 30.—Average Time Taken for Various Operations Connected with Building Concrete Arches in Subaqueous Tunnels.

Average time, in hours, form stood after filling.	Type of reinforcement.	Length of section, in feet.	Time, in hours, moving and erecting forms.		Time, in hours, placing concrete in arch.	Time, in hours, placing concrete in key.	Time, in hours, placing concrete in key and arch.	Total time, in hours, for moving, erecting, and filling.	Total time, in hours, per linear foot, for moving, erecting, and filling.	Remarks.
70	A day work	50	20		15	15.40	30.40	50.40	1.01	.....
			Moving	Erecting						
..	A day work	20	2	3	8.30	2.40	11.10	16.10	0.80	.....
53	B day work	20	2	3	10.40	11.20	22.00	27.00	1.35	Includes placing rods.
53	C day work	20	2	3	11.00	7.20	18.20	23.20	1.16	do.
53	D day work	20	2	3	9.50	4.35	14.25	19.25	0.91	do.
53	D piece work	20	2	3	6.15	2.05	8.20	13.20	0.65	do.
53	Sub-Type No. 1 piece work	20	2	3	6.00	3.00	9.00	14.00	0.70	do.

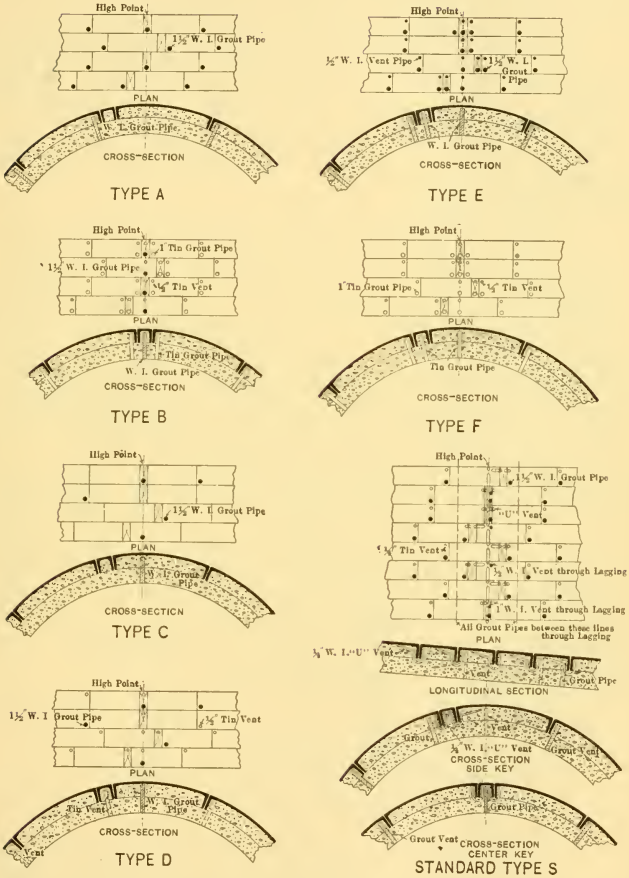

High Point
1½" W. I. Grout Pipe
PLAN
W. I. Grout Pipe
CROSS-SECTION
TYPE A
High Point
½" W. I. Vent Pipe
1½" W. I. Grout Pipe
PLAN
W. I. Grout Pipe
CROSS-SECTION
TYPE E
High Point
1" Tin Grout Pipe
1½" W. I. Grout Pipe
⅛" Tin Vent
PLAN
1" Tin Grout Pipe
W. I. Grout Pipe
CROSS-SECTION
TYPE B
High Point
1" Tin Grout Pipe
⅛" Tin Vent
PLAN
Tin Grout Pipe
CROSS-SECTION
TYPE F
High Point
1½" W. I. Grout Pipe
PLAN
W. I. Grout Pipe
CROSS-SECTION
TYPE C
High Point
1½" W. I. Grout Pipe
½" Tin Vent
PLAN
Tin Vent
W. I. Grout Pipe
CROSS-SECTION
Vent
TYPE D
High Point
1½" W. I. Grout Pipe
"U" Vent
⅛" Tin Vent
½" W. I. Vent through Lagging
1" W. I. Vent through Lagging
All Grout Pipes between these lines through Lagging
PLAN
⅜" W. I. "U" Vent
Vent
Grout Pipe
LONGITUDINAL SECTION
Vent
Grout
⅜" W. I. "U" Vent
Grout Vent
CROSS-SECTION SIDE KEY
Grout Pipe
Grout Vent
CROSS-SECTION CENTER KEY
STANDARD TYPE S

FIG. 23.

fixed in position and not subject to disturbance while placing the concrete. This system was used for about 80% of the total length of the tunnel, and proved entirely satisfactory. The machine used for grouting was the same as that used for grouting outside the metal lining.

The only compressed air available was the high-pressure supply, at about 90 lb.; a reducing valve, to lower this pressure to 30 lb. was used between the air line and the grouting machine. This was thought to be about as high a pressure as the green concrete arch would stand, and, even as it was, at one point a section about 2 ft. by 1 ft. was blown out.

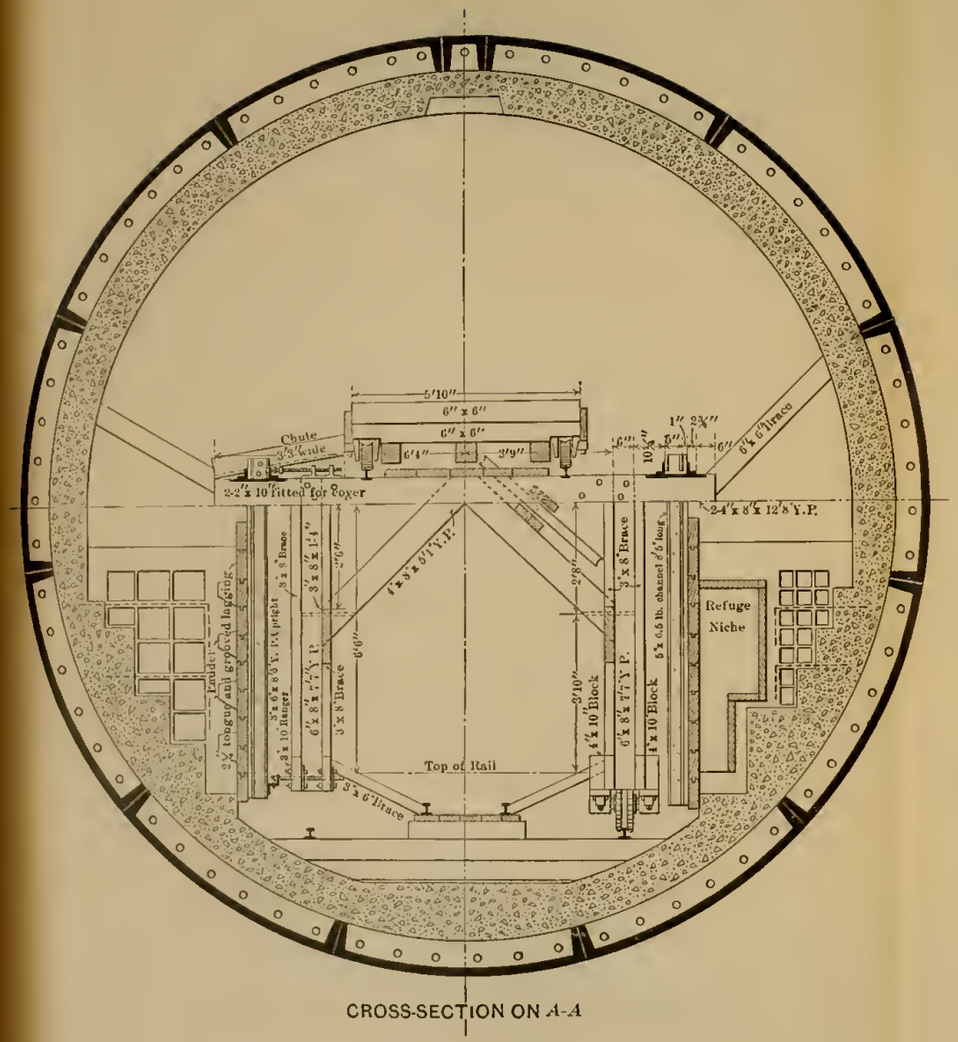
A rough traveling stage resting on the bottom step of the duct bench concrete was used as a working platform. In the earlier stages of the work the grouting was carried on in a rather haphazard manner, but, when the last system of grout and vent pipes was adopted, the work was undertaken systematically, and was carried out as follows:

Two 20-ft. lengths of arch were grouted at one time, and, in order to prevent the grout from flowing along the arch and blocking the pipes in the next lengths, a bulkhead of plaster was made at the end of every second length to confine the grout.

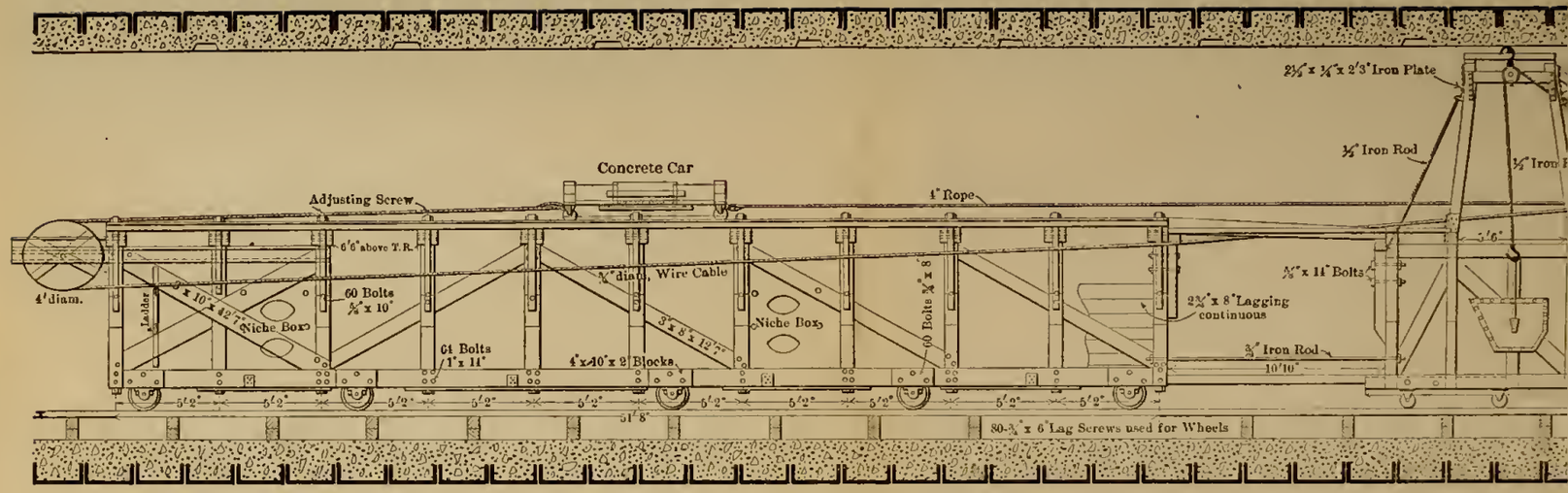
After a section had been grouted, test holes were drilled every 50 ft. along the crown to see that all the voids were filled; if not, holes were drilled in the arch, both for grouting and for vents, and the faulty section was re-grouted. An average of $\frac{3}{4}$ bbl. of cement and an equal quantity of sand was used per linear foot of tunnel. The average amount put in by one machine per shift was 15 bbl., and therefore the average length of tunnel grouted per machine per shift was 20 ft. The typical working force was:

1 Foreman	@	$3.75	per shift
1 Laborer running grout machine	"	2.00	" "
2 Laborers handling cement and sand	"	1.75	" "
1 Laborer tending valve and grout pipes	"	1.75	" "

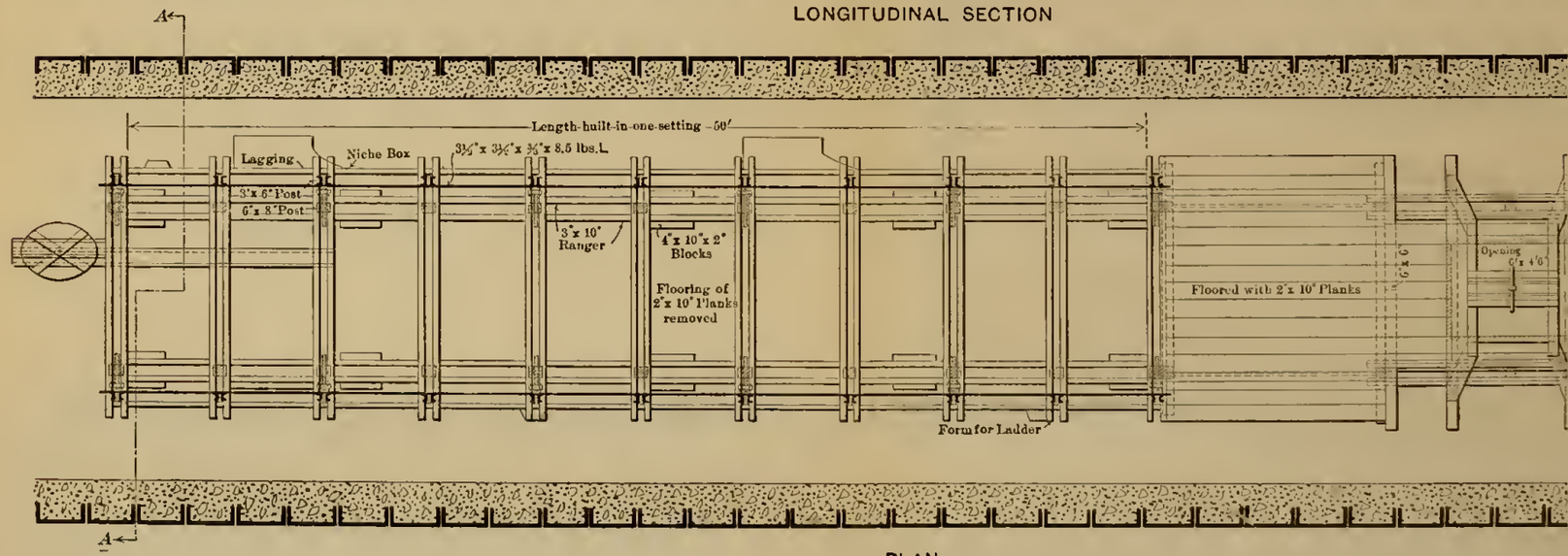
After the grouting was finished, the arches were rubbed over with wire brushes to take off discoloration, and rough places at the junctions of adjoining lengths or left by the block laggings were bush-hammered.



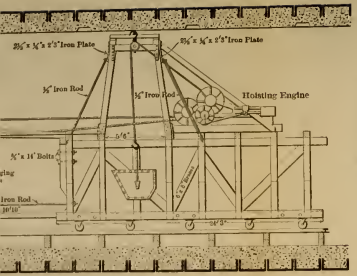
CROSS-SECTION ON *A-A*

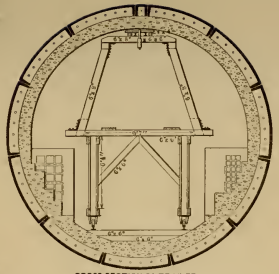


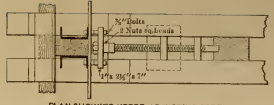
LONGITUDINAL SECTION

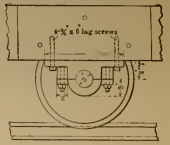


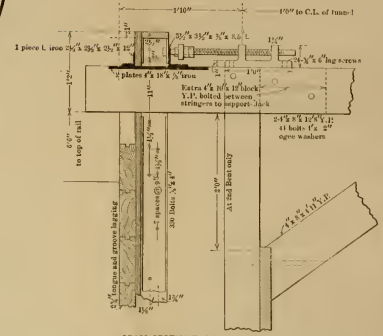
PLAN

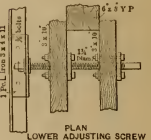

Hoisting Engine
Floored with 3" Planks
Posts

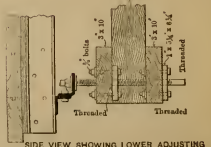

CROSS-SECTION OF TRAILER

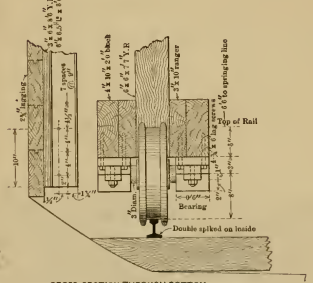

PLAN SHOWING UPPER ADJUSTING SCREW




1'10"
1'0" to C.L. of tunnel
Extra 4"x 10"x 15" block
Y.P. bolted between
stringers to support Jack
41 bolts 1"x 2½" cgree washers
Top of Rail
320 Bolts ¾"x 4"
CROSS-SECTION THROUGH TOP
TRAVELING CONCRETE FORM
FOR
FACE OF BENCH WALL
AS
USED IN RIVER TUNNELS


PLAN
LOWER ADJUSTING SCREW


Threaded
Threaded
SIDE VIEW SHOWING LOWER ADJUSTING SCREW


Top of Rail
Bearing
Double spiked on inside
CROSS-SECTION THROUGH BOTTOM

Face of Bench Concrete.—The form used for this portion of the work is shown on Plate XLV. It consisted of a central framework traveling on wheels, and, from the framework, two vertical forms were suspended, one on each side, and equal in height to the whole height of the bench. Adjusting screws were fitted at intervals both at top and bottom, and thus the position of the face forms could be adjusted accurately. The face forms were built very carefully of 3-in. tongued and grooved yellow pine, and one 50-ft. form was used for 3 000 ft. of tunnel without having the face renewed. Great care was taken to set these forms true to line and grade, as the appearance of the tunnel would have been ruined by any irregularity. Joints between successive lengths were finished with a V-groove.

The concrete was received at the form in dumping buckets; these were hoisted to the top of the form by a Lidgerwood hoister fixed to a trailer. The concrete was placed in the form by shoveling it from the traveling stage down chutes fitted to its side. The quantity of water to be used in the mixture needed careful regulation. The first few batches in the bottom had to be very wet, and were made with less stone than the upper portion, in order that the concrete would pack solidly around the niche box forms and other awkward corners.

The forms for the ladders and refuge niches were fastened to the face of the bench forms by bolts which could be loosened before the main form was moved ahead, and in this way the ladder and niche forms were left in position for some time after the main form was removed.

At first the forms were kept in place for 36 hours after finishing a length, but, after a little experience, 24 hours was found to be enough. In the summer, when the rise of temperature quickened the set, the time was brought down to 18 hours. The average time taken for a 50-ft. length was:

Laying concrete	4½ hours.
Interval for setting	18 "
Moving forms ahead and resetting	5 "
Total	27½ hours.

The typical working gang was:

Laying Concrete.

1 Foreman	@	$3.25	per shift.
2 Spaders	"	2.00	" "
8 Laborers	"	1.75	" "

Moving and Setting Forms.

1 Foreman	@	$4.00	per shift.
10 Laborers	"	1.75	" "

After the forms were removed, any rough places at the lower edge, where the concrete joins the "lip," were bush-hammered; no other cleaning work was done.

Duct Laying and Rodding.—The design and location of the ducts have already been described. It will have been seen that the duct-bench concrete was laid in steps, on which the ducts were laid, hence the maintenance of the grade and line in the ducts was an easy matter. The only complication was the expanded metal bonds, which were bent up out of the way of the arch forms and straightened out again after the arch forms had passed. The materials, such as ducts, sand, and cement, were brought into the tunnel by the regular transportation gang. The mortar was mixed in a wooden trough about 10 ft. long, 2 ft. 6 in. wide and 8 in. deep.

After the single-way ducts had been laid, all the joints were plastered with mortar, in order to prevent any foreign substance from entering the ducts. This was not necessary with the multiple duct, as the joints were wrapped with cotton duck. The ducts were laid on a laying mandrel, and, as soon as possible after the concrete was laid around a set of ducts, they were "rodded" with a rodding mandrel. Not many obstructions were met, and these were usually some stray laying mandrel which had been left in by mistake, or collections of mortar where the plastering of the single-way joints had been defective.

In the 657 000 duct ft. of conduit in the river tunnels only eight serious obstructions were met. That the work was of exceptionally high quality is shown by the fact that a heavy 3-in. lead cable has been passed through from manhole to manhole (450 ft.) in 6 min., and the company, engaged to lay the cables in these ducts, broke all its previous records for laying, not only for tunnel work, but also in the open.

Fig. 1, Plate XXXV, shows a collection of the tools and arrangements used in laying and rodding ducts. The typical working force was:

Laying Multiple Ducts.

1 Foreman	@	$3.50	per shift.
9 Laborers	"	1.75	" "

Laying Single-Way Ducts.

1 Foreman	@	$3.50	per shift.
8 Laborers	"	1.75	" "

Rodding Multiple Ducts.

1 Foreman	@	$3.50	per shift.
5 Laborers	"	1.75	" "

Rodding Single-Way Ducts.

1 Foreman	@	$3.50	per shift.
5 Laborers	"	1.75	" "

The average progress per 10-hour shift with such gangs was:

Laying multiple ducts	4 000 duct ft.
Laying single-way ducts	1 745 " "
Rodding multiple ducts	4 040 " "
Rodding single-way ducts	2 532 " "

No detailed description need be given of the concreting of the cross-passages, pump chambers, sumps, and other small details, the design of which has been previously shown. The concrete was finished on June 1st, 1909.

Period No. 6.—Final Cleaning Up.—June, 1909, to November, 1909.—As soon as all the concrete was finished, the work of cleaning up the invert was begun. A large quantity of débris littered the tunnels, and it was economical to remove it as quickly as possible. The remaining forms were first removed, and hoisting engines, supported on cross-timber laid across the benches, were set up in the middle of the tunnel at about 500-ft. intervals.

Work was carried on day and night, and about 169 ft. of single tunnel was cleared per 10-hour shift. Work was begun on May 28th, and finished on July 15th, 1909. For part of the time it was carried on at two points in each tunnel, working toward the two shafts, but when the work in the Weehawken Shaft, which was being done at the same time, blocked egress from that point, all material was sent out by the Manhattan Shaft.

The total quantity of material removed was 5 350 cu. yd., or about 0.44 cu. yd. per lin. ft. of tunnel. The average force per shift was:

In Tunnel.

3 Foremen	@	$3.25	per shift
1 Hoist engineer	"	3.00	" "
1 Signalman	"	2.00	" "
38 Laborers	"	1.75	" "

On the Surface.

1 Foreman	@	$3.25	per shift
1 Hoist engineer	"	3.00	" "
1 Signalman	"	2.00	" "
12 Laborers	"	1.75	" "

After the cleaning out had been done, the contractor's main work was finished. However, quite a considerable force was employed, up to November, 1909, in doing various incidental jobs, such as the installation of permanent ventilation conduits and nozzles at the intercepting arch near the Manhattan Shaft, the erection of a headhouse over the Manhattan Shaft, and collecting and putting in order all the miscellaneous portable plant, which was either sold or returned to store, sorting all waste materials, such as lumber, piping, and scraps of all kinds, and, in general, restoring the sites of the working yards to their original condition.

Concrete Mixing.

The plant used in mixing the concrete for the land tunnels was pulled down and re-erected before the concrete work in the river tunnels was begun. At the New York shaft two new bins for sand and stone were built, bringing the total capacity up to 950 cu. yd. Two No. 6 Ransome mixers, driven electrically by 30-h.p. General Electric motors, using current from the contractor's generators, were set up on a special platform in the intercepting arch.

At Manhattan the sand and stone were received from the bins in chutes at a small hopper built on the permanent upper platform of the intercepting arch. Bottom-dumping cars, divided by a partition into two portions, arranged to hold the proper quantities of sand and stone for a 4-bag batch of concrete, were run on a track on this upper platform, filled with the proper quantities of sand and stone, and then run back and dumped into the hoppers of the mixer. After mixing, the batch was run down chutes into the tunnel cars standing on the track below. The water was brought in pipes from the public supply. It was measured in barrels by a graduated scale within the barrels. The water was not put into the mixer until the sand and stone had all run out of the mixer hopper. The mixture was revolved for about 1½ min., or about 20 complete revolutions.

At Weehawken Shaft the mixing plant was entirely rebuilt. Four

large bins, two for sand and two for stone, were built in the shaft. Together, they held 430 cu. yd. of stone and 400 cu. yd. of sand. The sand and stone were dumped directly into the bins from the cars on the trestle which ran from the wharf to the shaft. The materials were run through chutes directly from the bins to the hoppers of the mixers, where they were measured. Two No. 6 Ransome mixers, electrically driven, were used here, as at New York, and, as there, the water was led into measuring tanks before being let into the mixer.

The quantity of water used in the various parts of the concrete cross-section, for a 4-bag batch consisting of 1 bbl. (380 lb.) of cement, 8.75 cu. ft. of sand, and 17.5 cu. ft. of stone, is given in Table 31.

TABLE 31.—Quantity of Water per 4-Bag Batch of Concrete, in U. S. Gallons.

Portion of cross-section.	Maximum.	Minimum.	Average.
Invert	40	20	26
Duct bench	36	21	27
Arch (excluding key)	37	19	25
Key of arch	27	15	20
Face of bench	31	22	27

The maximum quantities were used when the stone was dry and contained more than the usual proportion of fine material, the minimum quantity when the sand was wet after rain.

The resulting volumes of one batch, for various kinds of stone, are given in Table 32.

TABLE 32.—Volume of Concrete per Batch, with Various Kinds of Stone.

Mixture.	Description of Stone.		Resulting volume per barrel of cement, in cubic yards.	Remarks.
	Passed screen.	Retained on screen.		
1 : 2½ : 5	1½-in.	¾-in.	0.815	Measured in air.
1 : 2½ : 5	2½-in.	Run of crusher.	0.827	" " "
1 : 2½ : 5	.....	General average.	0.808*	Measured from plan.
1 : 2½ : 5	2-in.	1½-in.	0.768†	" " "

* Average for whole of River Tunnel section.

† Average from 7 400 cu. yd. in Land Tunnel section.

The sand used was practically the same for the whole of the river tunnel section, and was supposed to be equal to "Cow Bay" sand. The result of the mechanical analysis of the sand is shown on Plate XLVI. The stone was all trap rock. For the early part of the work it consisted of stone which would pass a 2-in. ring and be retained on a 1½-in. ring, in fact, the same as used for the land tunnels. This was found to be too coarse, and for a time it was mixed with an equal quantity of fine gravel or fine crushed stone. As soon as it could be arranged, run-of-crusher stone was used, everything larger than 2½ in. being excluded. About three-quarters of the river tunnel concrete was put in with run-of-crusher stone. The force was:

At Manhattan.

1 Foreman	@	$3.00	per shift
4 Men on sand and stone cars	"	1.75	" "
4 Men handling cement	"	1.75	" "
2 Men dumping mixers	"	1.75	" "

At Weehawken.

1 Foreman	@	$3.00	per shift
2 Men hauling cement	"	1.75	" "
2 Men dumping mixers	"	1.75	" "

The average quantity of concrete mixed per 10-hour shift was about 117 batches, or about 90 cu. yd. The maximum output of one of the mixers was about 168 batches, or 129 cu. yd. per 10-hour shift.

Transportation.

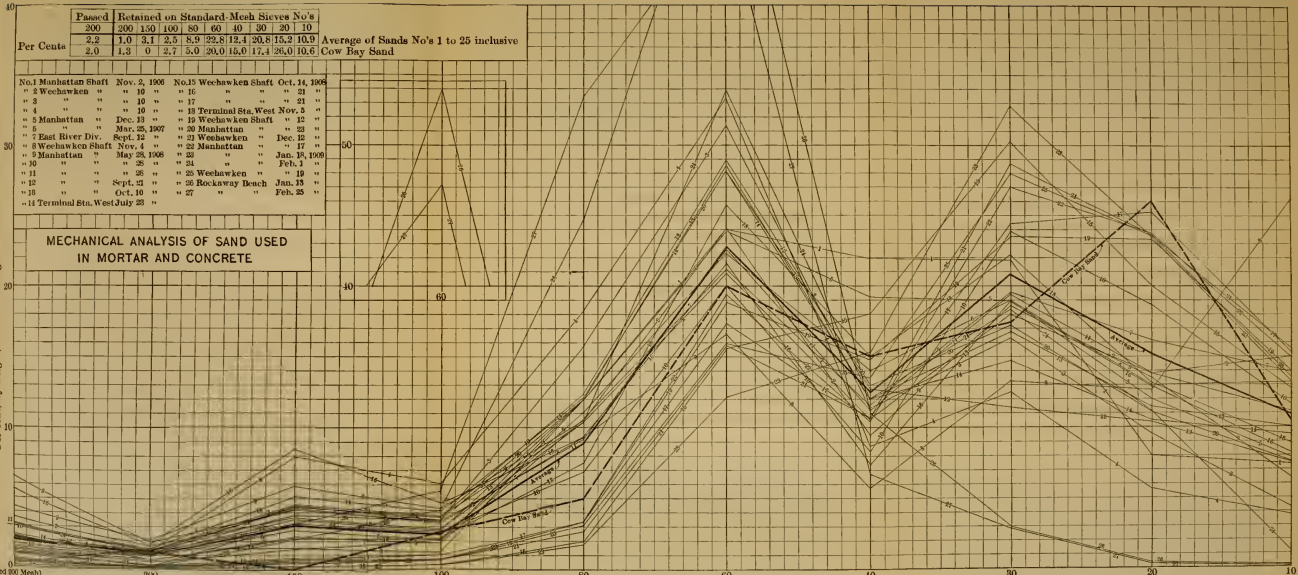
Surface Transportation.—At Manhattan the stone and sand were received in scows at the wharf on the river front. For the first part of the work, the wharf at 32d Street and North River was used, and while that was in use the material was unloaded from the scows into scale-boxes by a grab-bucket running on an overhead cable, and then teamed to the shaft. For the latter part of the work, the wharf used was at 38th Street and North River, where facilities for unloading were given to the contractor by the Pennsylvania Railroad Company which was the permanent lessee of the piers. The material was unloaded into scale-boxes by a grab-bucket operated by a derrick, and teamed to the shaft. When the scale-boxes arrived at the shaft they were lifted from the trucks by derricks and dumped into the bins.

	Passed	Retained on Standard-Mesh Sieves No's								
	200	200	150	100	80	60	40	30	20	10
Per Cents	2.2	1.0	3.1	2.5	8.9	22.8	12.4	20.8	15.2	10.9
	2.0	1.3	0	2.7	5.0	20.0	15.0	17.4	26.0	10.6

Average of Sands No's 1 to 25 inclusive
Cow Bay Sand

No. 1	Manhattan Shaft	Nov. 2, 1906		No. 15	Weehawken Shaft	Oct. 14, 1908	
" 2	Weehawken "	" 10 "		" 16	"	" 21 "	
" 3	" "	" 10 "		" 17	"	" 21 "	
" 4	" "	" 10 "		" 18	Terminal Sta. West	Nov. 5 "	
" 5	Manhattan "	Dec. 13 "		" 19	Weehawken Shaft	" 12 "	
" 6	" "	Mar. 25, 1907		" 20	Manhattan "	" 23 "	
" 7	East River Div.	Sept. 12 "		" 23	Weehawken "	Dec. 12 "	
" 8	Weehawken Shaft	Nov. 4 "		" 22	Manhattan "	" 17 "	
" 9	Manhattan "	May 28, 1908		" 23	" "	Jan. 18, 1909	
" 10	" "	" 28 "		" 24	" "	Feb. 1 "	
" 11	" "	" 28 "		" 25	Weehawken "	" 19 "	
" 12	" "	Sept. 17 "		" 26	Rockaway Beach	Jan. 15 "	
" 13	" "	Oct. 10 "		" 27	" "	Feb. 25 "	
" 14	Terminal Sta. West	July 23 "					

MECHANICAL ANALYSIS OF SAND USED IN MORTAR AND CONCRETE



At Weehawken all the stone and sand, with the exception of the stone crushed on the work, was received by water at the North slip. Here it was unloaded by a 2-cu. yd. grab-bucket and dumped into 3-cu. yd. side-tipping cars, which were hauled by a small steam locomotive over the trestle to the shaft, where they were dumped directly into the bins.

Before beginning the concrete lining, the 2-ft. gauge railway, which had been used for the surface transportation during the driving of the iron-lined tunnels, was taken up and replaced by a 3-ft. gauge track consisting largely of 30-lb. rails. The cars were 3-cu. yd. side-dumping, with automatic swinging sides. Two steam locomotives which were being stored at Weehawken (part of the plant from another contract), were used for hauling the cars in place of the electric ones used with the 2-ft. gauge railway.

Tunnel Transport.—The track used in the tunnel was of 2-ft. gauge, laid with the 20-lb. rails previously used in driving the iron-lined tunnels. The mining cars (previously mentioned in describing the driving of the iron-lined tunnels) were used for transporting the invert concrete, although, for most of the work, dumping buckets carried on flat cars were used. Several haulage systems were considered for this work, but not one of them was thought to be flexible enough to be used with the constantly changing conditions, and it was eventually decided to move all the cars by hand, because, practically all the work being down grade, the full cars could be run down by gravity and the empty ones pushed back by hand. Two men were allotted to each car, and were able to keep the traffic moving in a manner that would have been perhaps impossible with any system of mechanical haulage. This system was apparently justified by the results, for the whole cost of the tunnel transport, over an average haul of about 2 000 ft., was only about 50 cents per cu. yd., which will be found to compare favorably with mechanical haulage on similar work elsewhere, provided full allowance is made for the use of the plant and power.

Force Employed.—The average force employed on transport, both on the surface and in the tunnel, is shown in Table 33.

Costs.

During the work, careful records of the actual cost to the contractor of carrying out this work were kept by the Company's forces; these

costs include all direct charges, such as labor and materials, and all indirect charges such as head office, plant depreciation, insurance, etc., but do not include the cost of any financing, of which the Company had no information.

TABLE 33.—Average Force per Shift for Transportation in Two Tunnels.

Location.	Grade.	Rate.	Work in Progress.		
			Two inverts and two duct benches.	Two arches, two inverts, and two duct benches.	Four arches and one face of bench.
Tunnel...	Foreman	$3.00	2	2	2
	Laborer	1.75	24	28	70
	Switchmen	2.00	..	2	2
	Hoisting engineers.	3.00	2	4	5
Surface..	Foreman	3.00	1	1	2
	Laborers	1.75	8	8	15
	Teams	6.50	1	1	2

Field Engineering Staff.

The field staff may be considered as divisible into five main divisions:

(*A*).—Construction, including alignment,

(*B*).—Cost records,

(*C*).—Testing of cement and other materials of construction,

(*D*).—Photography,

(*E*).—Despatch-boat service.

(*A*).—*Construction* (*Inspection and Alignment*) *Staff.*—A comparatively large staff was maintained by the Company, and to this two causes contributed. In the first place, the contractor maintained no field engineering staff, because, early in the proceedings, it was arranged that the Company would carry out all this work, and thus avoid the overlapping, confusion, and lack of definite responsibility which often ensues when two engineering forces are working over the same ground. Even had the contractor maintained an engineering force, it would have been necessary for the Company to check most of the contractor's work.

In the second place, this work gave rise to a number of special surveys, tests, borings, and observations of various kinds, most of which were kept up as a part of the regular routine work, and this necessi-

tated a staff. Also, for a whole year, active progressive work was at a standstill while the pile tests were going on.

(*B*).—*Cost Records Staff.*—A distinct feature was made of keeping as accurately as possible detailed records of the actual cost to the contractor of carrying out the work. A small staff of clerks, retained solely for this purpose, tabulated and recorded the information furnished by the members of the construction staff. About $12 000, altogether, was spent in salaries in this department, and it may be considered an extremely wise investment, for, not only is the information thus obtained of great value and interest in itself, but it also puts the Company in an excellent position should any claim or discussion arise with the contractor.

(*C*).—*Cement-Testing Department.*—As the Company furnished the cement to the contractor, it became incumbent to make careful tests of the quality. A cement-testing laboratory was established at the Manhattan Shaft offices, under the charge of a cement inspector who was furnished with assistants for sampling, shipping, and testing cement. All materials used on the work, such as bricks, sand, stone, water-proofing, etc., were tested here, with the exception of metals, which were under the charge of a metal inspector reporting directly to the head office. This department cost about $10 000 for salaries and $3 000 for apparatus and supplies, or about $13 000, in all.

There were 800 000 bbl. of cement tested, and samples from 2 100 000 brick. A large amount of useful information has resulted from the work of this laboratory.

(*D*).—*Photography.*—It was desired to keep a complete photographic record of the progress of the work, and therefore a photographer was appointed, with office room at the Manhattan Shaft. The photographer took all the progress photographs on the work of the North River Division, made photographic reductions of all drawings and plans, made lantern slides of all negatives of a more important nature, and, in addition, during the period of compressed air, analyzed the samples of compressed air, brought into the office for the purpose, for the amount of CO_2 present. About $8 000 was spent on this department.

(*E*).—*Despatch-Boat Service.*—To provide access to the New Jersey side, a despatch boat was purchased. This boat was at first (June, 1904) chartered, and in May, 1905, was bought outright, and ran on regular schedules, day and night. It continued in the service until

April, 1909, when it was given up, as the tunnels were so far completed that they provided easy access to New Jersey. The cost of the boat (second-hand) was about $3 000. It was then thoroughly overhauled and the cabin remodeled. The monthly cost, when working a 12-hour shift, was $270 for manning, $65 for supplies, and $64 for coal. On two 12-hour shifts, the monthly cost was $533 for manning, $100 for supplies, and $96 for coal. About 100 000 passengers were carried during the boat's period of service, and the total cost was about $37 500.

For the major part of the period embraced by this paper, B. H. M. Hewett, M. Am. Soc. C. E., served as General Resident Engineer, in charge of the Field Work as a whole.

W. L. Brown, M. Am. Soc. C. E., was at first Resident Engineer of the work constructed from the Manhattan Shaft, while H. F. D. Burke, M. Am. Soc. C. E., was Resident Engineer of the work constructed from the Weehawken Shaft. After the meeting of the shields, Mr. Burke left to take up another appointment, and from that time Mr. Brown acted as Resident Engineer.

It may be said, without reflecting in any way on the manufacturers, that the high standard of all the metal materials also testified to the efficient inspection conducted under the direction of Mr. J. C. Naegeley.

It is impossible to close this brief account of these tunnels without recording the invaluable services at all times rendered by the members of the Company's field staff. Where all worked with one common aim it might seem invidious to single out names, but special credit is due to the following Assistant Engineers: Messrs. H. E. Boardman, Assoc. M. Am. Soc. C. E., W. H. Lyon, H. U. Hitchcock, E. R. Peckens, H. J. Wild, Assoc. M. Am. Soc. C. E., J. F. Sullivan, Assoc. M. Am. Soc. C. E., and R. T. Robinson, Assoc. M. Am. Soc. C. E. Mr. C. E. Price was in charge of the cement tests throughout the entire period, and brought to his work not only ability but enthusiasm. Mr. H. D. Bastow was in charge of the photographic work, and Mr. A. L. Heyer of the cost account records, in which he was ably seconded by Mr. A. P. Gehling, who, after Mr. Heyer's departure, finished the records and brought them into their final shape. The organization of the Company's field engineering staff is shown graphically by Fig. 24.

FIELD ORGANIZATION OF THE O'ROURKE ENGINEERING CONSTRUCTION COMPANY FOR THE BUILDING OF THE PENNSYLVANIA RAILROAD TUNNELS INTO NEW YORK CITY—NORTH RIVER DIVISION. SECTIONS GY EAST, GY WEST SUPPLEMENTARY, GY WEST, AND GJ.

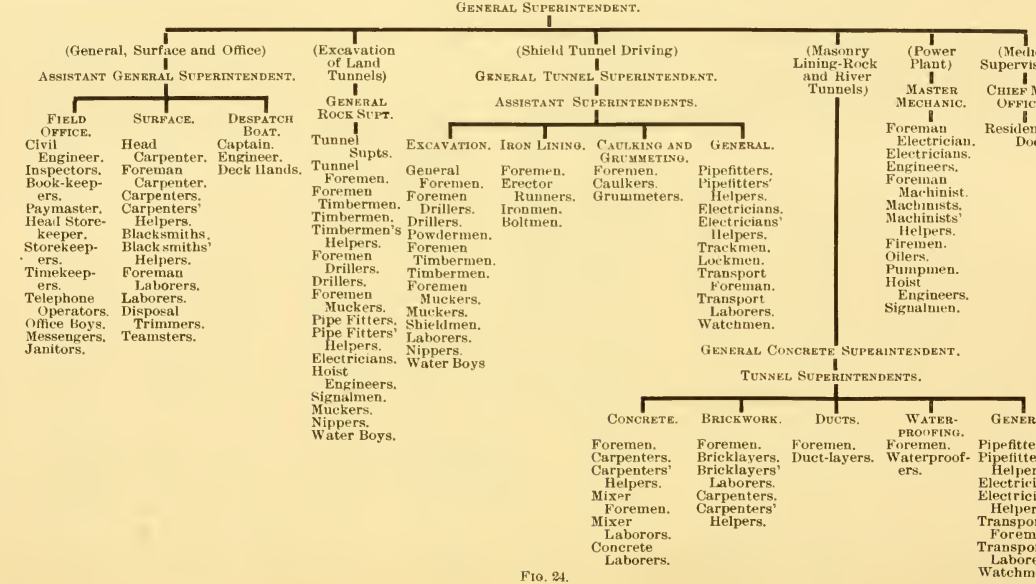


FIG. 24.

Contractor's Organization.—The contracting firm which did the work described in this paper was the O'Rourke Engineering Construction Company, of New York City. The President of this Company was John F. O'Rourke, M. Am. Soc. C. E., the Vice-President was F. J. Gubelman, Assoc. M. Am. Soc. C. E. The General Superintendent was Mr. George B. Fry, assisted by J. F. Sullivan, Assoc. M. Am. Soc. C. E. The duties of General Tunnel Superintendent fell to Mr. Patrick Fitzgerald. The generally pleasant relations existing between the Company and the contractor's forces did much to facilitate its execution.

The organization of the Contractor's field staff is shown on Fig. 25.

PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD COMPANY.
NORTH RIVER DIVISION.

SECTIONS GY EAST, GY WEST SUPPLEMENTARY, GY WEST, GJ, AND I, *i. e.*, FROM 10TH AVENUE, MANHATTAN, TO THE WEEHAWKEN SHAFT, FIELD ENGINEERING STAFF ORGANIZATION.

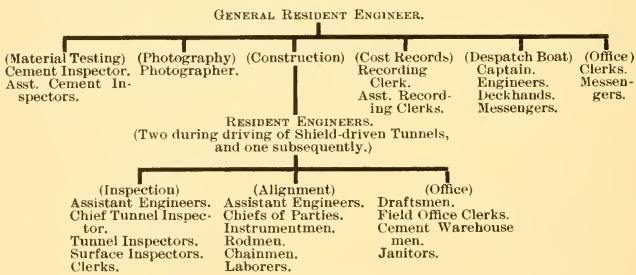


FIG. 25.

In conclusion, the writers cannot forego the pleasure of expressing their deep obligation to Samuel Rea, M. Am. Soc. C. E., as representing the Management of the Company, to the Chief Engineer, Charles M. Jacobs, M. Am. Soc. C. E., and to James Forgie, M. Am. Soc. C. E., Chief Assistant Engineer, for their permission to write this paper, and also to all the members of the field office staff for their great and unfailing assistance in its preparation.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1156

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

THE TERMINAL STATION-WEST.*

By B. F. Cresson, Jr., M. Am. Soc. C. E.

Location of Work.—The area covered by the work of the Terminal Station-West is bounded as follows: By the east line of Ninth Avenue; by the south side of 31st Street to a point about 200 ft. west of Ninth Avenue; by a line running parallel to Ninth Avenue and about 200 ft. therefrom, from the south side of 31st Street to the boundary line between the 31st and 32d Street properties; by this line to the east line of Tenth Avenue; by the east line of Tenth Avenue to the boundary line between the 32d and 33d Street properties; by this line to the east line of Ninth Avenue. The area is approximately 6.3 acres.

House-Wrecking.—The property between Ninth and Tenth Avenues was covered with buildings, 94 in number, used as dwelling and apartment houses and church properties, and it was necessary to remove these before starting the construction. Most of the property was bought outright by the Railroad Company, but in some cases condemnation proceedings had to be instituted in order to acquire possession. In the case of the property of the Church of St. Michael, fronting on Ninth Avenue, 31st and 32d Streets, the Railroad Company agreed to purchase a plot of land on the south side of 34th Street, west of Ninth

* Presented at the meeting of April 6th, 1910.

Avenue, and to erect thereon a church, rectory, convent, and school, to the satisfaction of the Church of St. Michael, to hand over these buildings in a completed condition, and to pay the cost of moving from the old to the new buildings, before the old properties would be turned over to the Railroad Company.

The house-wrecking was done by well-known companies under contract with the Railroad Company. These companies took down the buildings and removed all the materials as far as to the level of the adjacent sidewalks. The building materials became the property of the contractors, who usually paid the Railroad Company for the privilege of doing the house-wrecking. The work was done between April and August, 1906, but the buildings of the Church of St. Michael were torn down between June and August, 1907.

The bricks were cleaned and sold directly from the site, as were practically all the fixtures in the buildings. The stone fronts were broken up and left on the premises. Some of the beams were sold on the premises, but most of them were sent to the storage yards. Some of the lath and smaller timber was sold for firewood, but most of it was given away or burned on the premises.

Contracts and Agreements.—The main contract, awarded to the New York Contracting Company-Pennsylvania Terminal on April 28th, 1906, included about 502 000 cu. yd. of excavation (about 90% being rock), 17 820 cu. yd. of concrete walls, 1 320 000 lb. of structural steel, 638 000 ft., B. M., of framed timber, etc., etc.

This contract was divided into two parts: "Work In and Under Ninth Avenue" and "Work Between Ninth and Tenth Avenues," and unit prices were quoted for the various classes of work in each of these divisions. The prices quoted for excavation included placing the material on scows supplied by the Railroad Company at the pier at the foot of West 32d Street, on the North River; there was a clause in the contract, however, by which the contractor could be required to make complete disposal of all excavated material at an additional unit price, and this clause was enforced on January 1st, 1909, when about 94% of the excavation had been done.

For the purpose of disposing of the excavated material in the easterly portion of the Terminal, the New York Contracting Company-Pennsylvania Terminal had excavated under Ninth Avenue a cut which came to the grade of 32d Street about midway between Ninth and

Tenth Avenues, and a trestle was constructed from this point over Tenth Avenue and thence to the disposal pier at the foot of West 32d Street.

On May 11th, 1906, the work of excavation was commenced on the east side of Ninth Avenue, and on July 9th, 1906, on the south side of 31st Street, between Ninth and Tenth Avenues. From the beginning, the excavation was carried on by day and night shifts, except on Sundays and holidays, until January, 1909, except that during the period from November, 1907, to October, 1908, the night shift was discontinued.

Geology.—The rock encountered may be classed as "gneiss"; its character varied from granite to mica schist. It was made up of quartz, feldspar, and mica, and there were also some isolated specimens of pyrites, hornblend, tourmaline, and serpentine. On the south side of the work, just west of Ninth Avenue, there were excellent examples of "contortions" of veins of quartz in the darker rock. On the east side of Ninth Avenue, near the north end of the work, glacial marks were found on the rock surface. The general direction of the stratification was north 5° west, and the general incline about 60° with the horizontal. As a rule, the rock broke sharply along the line of stratification. On the south side it broke better than on the north side, where it was usually softer and more likely to slide; and this, together with the fact that in winter it was subject to alternate freezing and thawing and in summer to the direct rays of the sun, made it rather difficult to get a good foundation for the retaining walls.

Work In and Under Ninth Avenue.

General Description.—The work involved the excavation of about 375 ft. of the full width of Ninth Avenue to an average depth of about 58 ft., and the construction over this area of a steel viaduct, the deck of which was about 24 ft. below the surface, for the ultimate support of the Ninth Avenue structures.

The following estimated quantities appear in the contract: Excavation of rock, 72 600 cu. yd.; excavation of all materials except rock, 9 300 cu. yd.; concrete (1:3:6) in abutments, etc., 1 680 cu. yd.; timber, 504 000 ft., B. M.; structural steel, 1 320 000 lb., etc.

While this excavation was being done it was necessary to support and maintain the three-track elevated railway structure of the Inter-

borough Rapid Transit Company, of which 18 columns, or a length of about 340 ft., were affected, the two-track surface railway structure of the New York City Railway Company, and various pipes, sewers, and conduits, and to maintain all surface vehicular and pedestrian traffic. All structures were left in place with the exception of the pipes, most of which were temporarily cut out. The 48-in. brick sewer in the center of Ninth Avenue was broken, and the sewage was pumped across the excavation through a smaller pipe.

The general method adopted was as follows: The east and west sides of the avenue were closed, vehicular traffic was turned into the center, and a trestle for pedestrians was constructed west of the westerly elevated railway columns. All structures were then supported on transverse girders, running across the avenue, below the surface, and these rested on concrete piers on the central rock core. The sides of the avenue were then excavated to sub-grade, and the permanent steel viaduct was erected on both sides of the avenue as close as possible to the central rock core. The weight of all structures was then transferred to the permanent steel viaduct, erected on the sides of the avenue, by timber bents under the transverse girders resting on the permanent steel viaduct, and all weight was thus taken off the central rock core. This core was then excavated to sub-grade, the permanent viaduct was completed, and all structures were placed on its deck, using concrete piers and timber bents.

The design and erection of the permanent steel viaduct and the permanent foundations on its deck were done under another contract, apart from the North River Division work, and are not described in this paper.

Elevated Railway Structure of the Interborough Rapid Transit Company.—The Ninth Avenue Elevated Railway was built between 1877 and 1880 as a two-track structure, the design being such as to permit a third or central track to be added later, and this was built in 1894. It is supported on columns under the outside tracks, about 43 ft. from center to center longitudinally and 22 ft. 3 in. from center to center transversely, the central track being carried by transverse girders between the columns.

The columns carrying the structure are of fan top design, with the points of bearing near the extremities at the top; each of the outside tracks is supported on two longitudinal latticed girders and the central

FIG. 1.

FIG. 2.

FIG. 3.

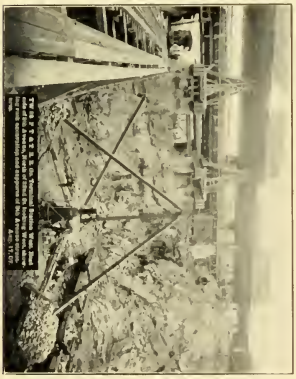


FIG. 4.

track on two plate girders; between the columns, transverse girders are spliced to the outside track cross-frames, and carry the central track system. It was not thought desirable to put brackets on the columns near the street level to support the structure temporarily, and, as there is an expansion joint at each column, and as the transverse girders carrying the central track system are not rigidly attached to the longitudinal girders carrying the outside tracks, the central track could not be supported by supporting the outside tracks; therefore, independent supports for each track, in the form of overhead girders, had to be provided. The columns rest on brick piers, each having four 2-in. anchor-bolts. The brick foundations on the west side are wide in order to allow a 24-in. water main to pass directly beneath the columns. The foundations are usually on rock.

Fig. 1, Plate XLVII, shows the elevated railway structure and the street surface prior to the commencement of the work.

The east track is used for north-bound local trains, the west track for south-bound local trains, and the central track for south-bound express trains between 7 and 9.30 A. M. and for north-bound express trains between 2.30 and 7 P. M. It is said that an average of 90 000 passengers are carried over this structure every 24 hours.

Surface Railway Structure of the New York City Railway Company.—This is an electric surface railway of the ordinary type, the rail and slot being bedded in concrete, with cast-iron yokes every 5 ft. There are manholes every 100 ft., and cleaning-out holes every 15 ft. Power conduits are bedded in the concrete on the east side of the east track.

Forty-eight-Inch Brick Sewer.—This sewer was in the center of Ninth Avenue, with the invert about 12 ft. below the surface, and manholes about 100 ft. apart, and had to be abandoned in this position to allow the transverse girders to be put in place to carry all structures while the excavation was being done.

Twenty-four-Inch Cast-Iron Water Main.—This water main was laid under the west elevated railway columns, with its top about 3 ft. below the surface, a space being left for it in the brick foundations, and a large column base casting being used to span it. Valves were installed, one north of 33d Street and one south of 31st Street, prior to excavating near the pipe, so that if it was broken the water could be shut off promptly.

Street Surface.—It was the original intention to close and excavate the east side of the avenue and to erect there a street-traffic trestle before closing the west side, but, at the contractor's request, both sides were closed, and all vehicular traffic was turned into the center. A light trestle on the west side of the avenue provided for pedestrian traffic.

Other Sub-surface Structures.—There were various gas mains, water mains, electric conduits, manholes, hydrants, etc., in the avenue, and most of these were cut out temporarily, at the contractor's request, to be replaced subsequently.

Supports for Elevated Railway Structure.—As stated previously, the central track had to be supported independently.

The overhead girders, known as girders "B", were therefore designed as shown on Fig. 1, and put in place as shown on Figs. 2 and 3. The outside tracks were blocked directly on these girders, and the central track was supported by blocking up the transverse girders on I-beams placed between the girders "B"; and no blocking was placed between the girders "B" and the longitudinal girders carrying the central track. The weight on each column was assumed to be 172 000 lb.

Supports for Surface Railway Structure.—A uniform load of 3 000 lb. per lin. ft. of single track, with the weight of a car at 39 000 lb., was assumed. Several feet of earth, between the structure and the rock, were mined out, and the structure was supported on I-beams and posts, and ultimately on the transverse girders by using timber bents under the I-beams, as shown on Fig. 3.

Water Mains and Sewer.—Cradles were designed for the support of the 48-in. and 24-in. water mains, resting on the transverse girders, and the 48-in. cast-iron sewer on the east side of the avenue was carried on I-beams bracketed to the ends of the transverse girders, as shown on Figs. 1 and 2.

Girders "C."—The transverse girders below the street surface, referred to above, were known as girders "C," and they were put in place at first resting on concrete piers on the central core; the weight of all structures was placed on them while the sides of the avenue were being excavated, and the sides of the viaduct were being built. The ends of these girders were then picked up on the sides of the viaduct, and, spanning the central rock core, carried all structures

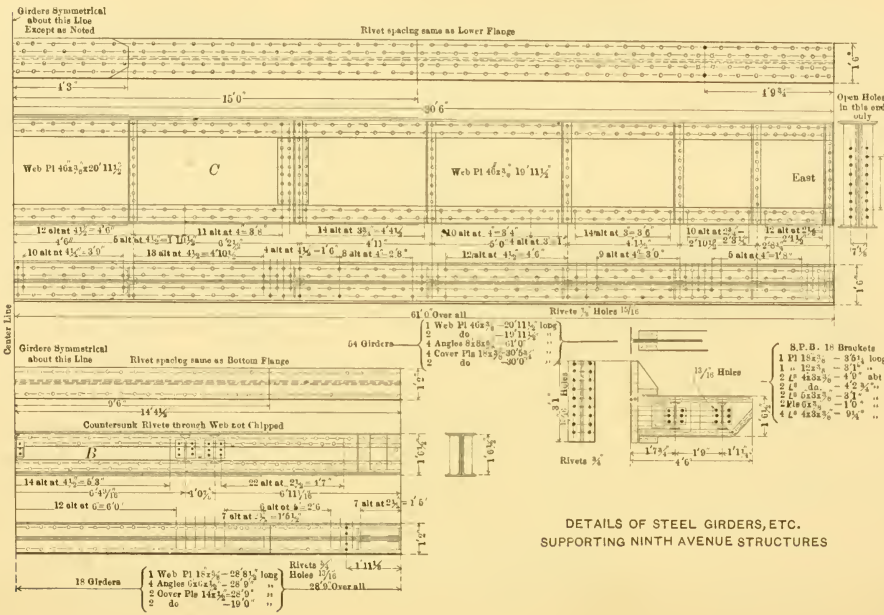

Girders Symmetrical about this Line Except as Noted
Rivet spacing same as Lower Flange
Open Holes in this end only
Web Pl 40x3/8" 20' 11 1/2"
C
Web Pl 40x3/8" 10' 11 1/2"
East
Center Line
61' 0" Over all
Rivets 7/8" Holes 15/16
54 Girders
1 Web Pl 40x3/8" — 20' 11 1/2" long
2 do — 12' 11 1/2" "
4 Angles 8x8x1" — 61' 0"
4 Cover Pls 18x3/8" — 30' 5 1/2"
2 do — 30' 0"
S.P.B. 18" Brackets
1 Pl 18x3/8" — 3' 5 1/4" long
1 " 12x3/8" — 3' 1" "
2 L's 4x3x7/16" — 4' 0" abt
2 L's do. — 4' 2 3/4" "
2 L's 6x3x7/16" — 3' 1" "
2 Pls 6x3/8" — 1' 0" "
4 L's 4x3x3/8" — 9 1/4" "
13/16 Holes
Rivets 3/4"
Girders Symmetrical about this Line
Rivet spacing same as Bottom Flange
Countersunk Rivets through Web not Chipped
B
18 Girders
1 Web Pl 18"x3/8" — 28' 8 1/2" long
4 Angles 6x4x7/16" — 28' 0" "
2 Cover Pls 14"x3/8" — 28' 0" "
2 do — 19' 0" "
Rivets 3/4" Holes 13/16
28' 9" Over all
DETAILS OF STEEL GIRDERS, ETC.
SUPPORTING NINTH AVENUE STRUCTURES

FIG. 1.

while the core was being excavated and the viaduct completed. New foundations were then placed on the deck of the viaduct to carry all structures.

Fifty-four of these girders were required, each weighing about 19 000 lb. The bents carrying the ends of these girders on the sides of the viaduct are shown on Fig. 2. They were of long-leaf yellow pine. These girders were located so that a cradle could be laid on them east of the elevated railway structure to carry a proposed 48-in. cast-iron water main.

Girders "B."—Eighteen of these girders were required, each weighing about 6 000 lb. The timber bents supporting these girders, shown on Fig. 2, were of long-leaf yellow pine.

The total weight, including the elevated railway structure, surface railway structure, pipes, etc., supported during the work, amounted to about 5 000 tons.

Details of the Work.—The method in general is shown on Figs. 4 and 5. At first the east side of the avenue was closed and excavated down to rock, the earth was mined out under alternate yokes of the surface railway structure, and temporary posts were placed under the yokes to support the structure while the remainder of the earth was being removed. Then needle-beams and posts were placed under each yoke. The concrete forming the track structure was then enclosed with planking to prevent it from cracking and falling. I-beams were then placed under the needle-beams carrying the structures, and these were carried on posts; they were changed alternately until the excavation had been taken out to a depth of about 16 ft. below the surface. In placing these I-beams, heavier blocking was used in the center of the span than at the ends where the bents would come, to prevent the subsidence of the track owing to the sag in the I-beams. As much excavation, to a depth of about 20 ft., was taken out adjoining the elevated railway foundations as could be done with safety. Fig. 2, Plate XLVII, shows this condition of the work. The 48-in. brick sewer was broken, and the sewage was pumped across the excavation.

The overhead girders "B" were then put in place, and two of the girders "C" were used as temporary shoring girders at each column. These, as shown by Fig. 3, Plate XLVII, were placed parallel to the elevated railway, with blocking between them and the girders "B."

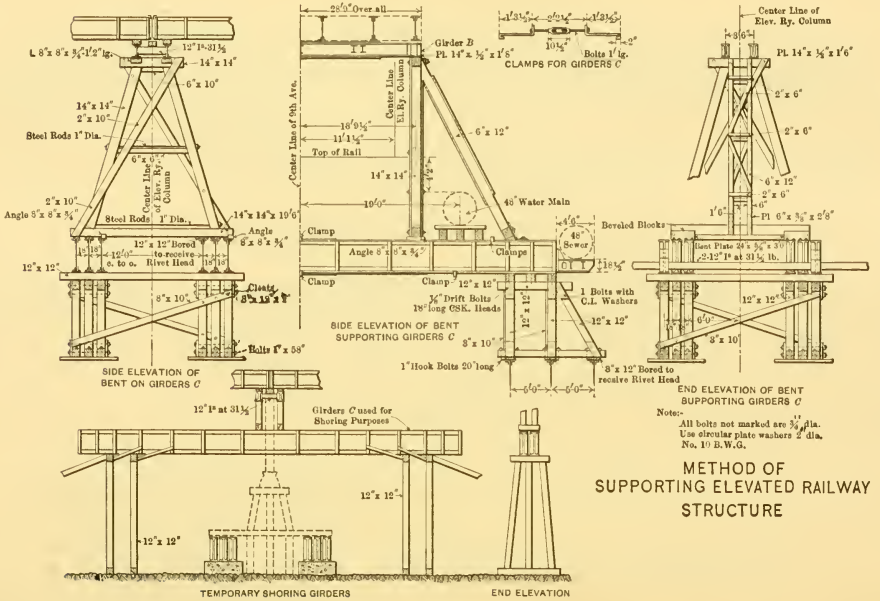
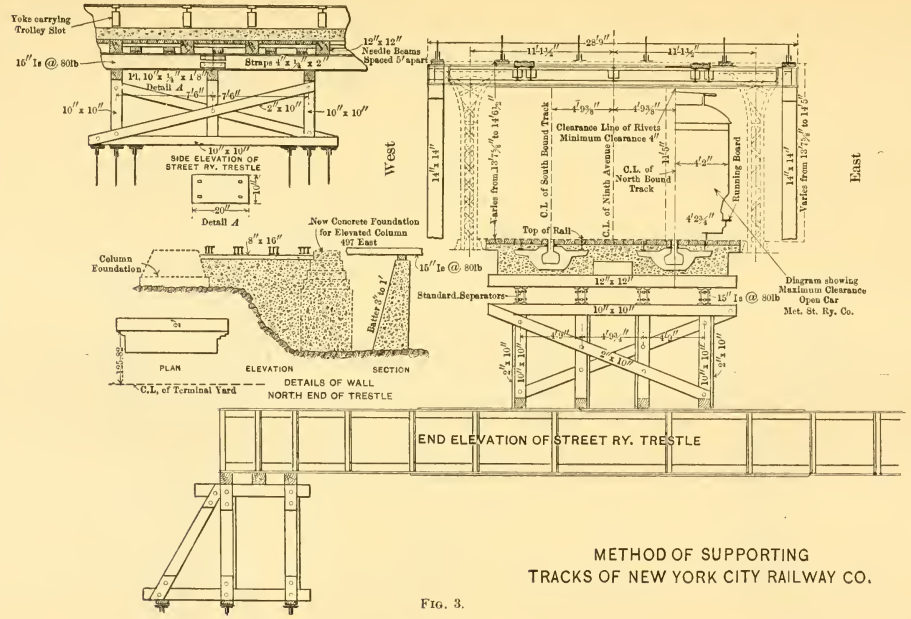
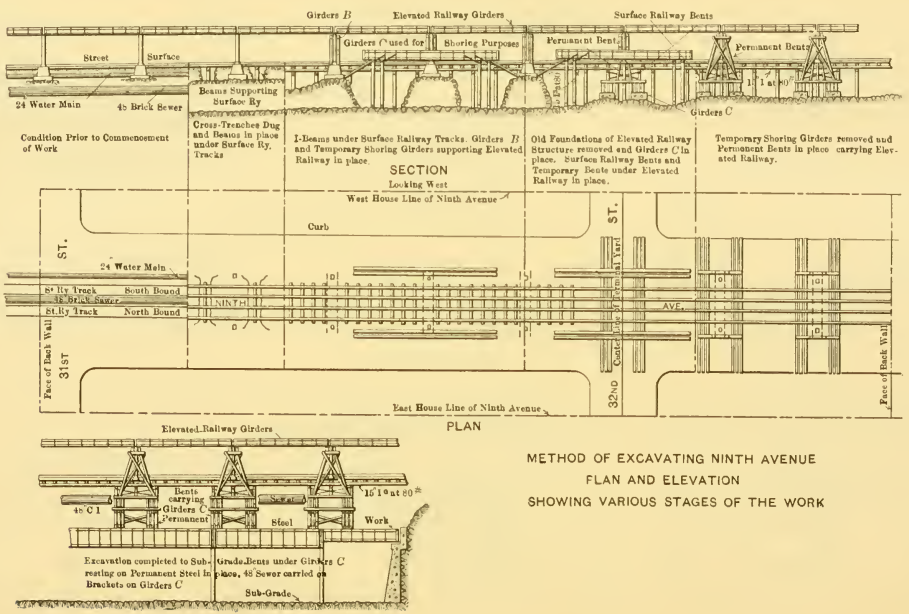

SIDE ELEVATION OF BENT ON GIRDERS C
SIDE ELEVATION OF BENT SUPPORTING GIRDERS C
CLAMPS FOR GIRDERS C
END ELEVATION OF BENT SUPPORTING GIRDERS C
Notes:-
All bolts not marked are ¾" dia.
Use circular plate washers 2" dia. No. 10 B.W.G.
METHOD OF SUPPORTING ELEVATED RAILWAY STRUCTURE
TEMPORARY SHORING GIRDERS
END ELEVATION

FIG. 2.



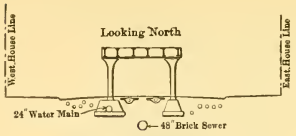
METHOD OF SUPPORTING TRACKS OF NEW YORK CITY RAILWAY CO.

FIG. 3.



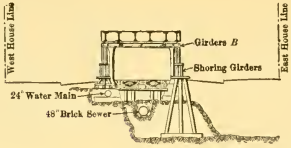
METHOD OF EXCAVATING NINTH AVENUE
FLAN AND ELEVATION
SHOWING VARIOUS STAGES OF THE WORK

FIG. 4.



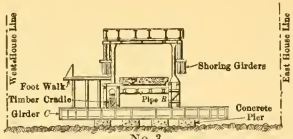
No. 1

Condition Prior to Commencement of Work



No. 2

East side of Avenue cut down about 20 ft. Beams with Supporting Posts placed under Surface Railway Tracks. Girders *B* and Temporary Shoring Girders *C* for supporting Elevated Ry. in place.

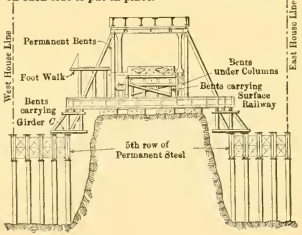


No. 3

I[s] in place under Surface Ry. Tracks. Elevated Ry. carried on Temporary Shoring Girders, and Girders *C* in place. 24" Water Main carried on Timber Cradle and sewage carried through Pipe *R*. Foot Walk carried on Girders *C* in place on West Side of Avenue

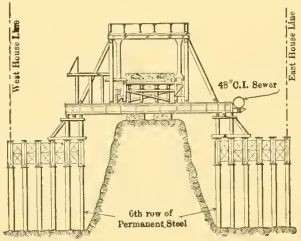
No. 4

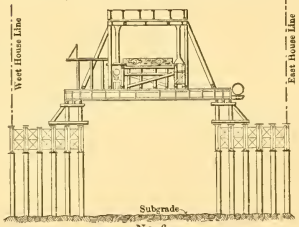
Elevated Railway carried on Bents under Columns. Temporary Shoring Girders removed and Permanent Bents resting on Girders *C* in place. Bents in place on Girders *C* carrying Surface Railway. East and West sides of Avenue excavated down to Sub-Grade and Five rows of Permanent Steel in place on each side. Bents erected on Permanent Steel to catch ends of Girders *C* while 2 outside Concrete Piers are removed and 6th row of Permanent Steel on each side is put in place.



No. 5

Two outside Concrete Piers removed and 6th row of Permanent Steel in place. Girders *C* carrying all structures now resting on Bents on Permanent Steel. 48"C.I. Sewer carried on Brackets on Girders *C*.





No. 6

Excavation Completed

FIG. 5.

METHOD OF
EXCAVATING NINTH AVENUE
SECTIONS SHOWING
VARIOUS STAGES OF WORK

Double bents, independent of each other, were placed under the ends of these temporary shoring girders, and these were braced securely to prevent possible dislodgment during the removal of the rock. The weight of the structure was then taken by jacking up the girders near the bents until the column was lifted off the old foundation; blocking was put in between the girders and the bents during the jacking, so that when the jacks were released the base of the column was still clear of the old foundation. One 80-ton jack was used for this purpose, and the general method is shown by Fig. 1, Plate LII.

Temporary raker braces were placed against the structure to prevent lateral movement. Four sets of these temporary shoring girders were used in this manner, two sets starting at the north end and two sets at about the middle of the work, and these sets were moved south as they were released.

The columns being thus supported on temporary shoring girders, the old foundations were removed and the excavation was taken down to a level about 16 ft. below the surface.

Two sets of three of the girders "C" were then put in place under the avenue at each column, each set being placed on four concrete piers 6 ft. square with spaces of 4 ft. between them, so that the outside of the outside pier would be 18 ft. from the center of the avenue and 32 ft. from the house line. This is shown on Fig. 5 and on Fig. 3, Plate XLVII. Four small piers were used, as they could be more easily removed than one continuous pier. The girders "C" were set to line and grade, and the piers were built under them, great care being taken to get the concrete well under the girders so as to give a firm bearing.

After these girders "C" were in place it was necessary to remove the temporary shoring girders before the bents could be erected on girders "C" to support girders "B," being in the same plane; and provision had to be made to support the structure while this was being done. Therefore, double bents were erected directly beneath the columns, as shown by Figs. 2, 4, and 5, and by Fig. 3, Plate XLVII. These were built with their sills resting on the girders "C," and blocking was put in between the sills and the rock to carry the full weight of the structure. Later, when the weight of the structure was carried on the permanent bents, this blocking was knocked out, but the bents were left in to carry the weight of the column itself, which was swing-

ing more or less from the structure above. The weight of the structure was placed on these bents directly beneath the columns by jacking up the temporary girders again, putting blocking between the bents and the base of the columns, and taking out the blocking which had been put in previously under the temporary shoring girders. The 24-in. water main was carried over the excavation on cables from the temporary shoring girders, except when they were being jacked up, at which time posts were placed beneath it.

Anchor-bolts were put in place between the column bases and the bents directly beneath, in order to increase the lateral stiffness, and raker braces were also used. This having been done, the temporary shoring girders were moved south to the next column, where the process was repeated. The timber bents, shown in detail by Fig. 2, were then put in place as shown by Figs. 4 and 5, and by Fig. 3, Plate XLVII. These bents were framed as tightly as possible, using generally a 20-ton jack, and they were erected simultaneously at each pair of columns. The weight was taken on these columns by jacking up directly beneath the column base and taking out the blocking between this base and the bent directly beneath the column. On releasing the jack the weight was transferred to the permanent timber bents, and the east and west columns of each pair were transferred on the same day. One 80-ton jack was used on the easterly columns and two were necessary on the westerly columns, one on each side of the 24-in. water main. The raker braces of these permanent bents were not framed as tightly as the main posts, in order that the main post should carry the entire weight and the raker braces merely steady the structure.

Timber bents were erected on girders "C" to carry the I-beams under the surface railway structure, as shown on Fig. 3, and all temporary posts under these I-beams were removed. The bents were framed with a jack, as tightly as possible, and very little settlement of the track occurred.

A cradle was then built under the 24-in. water main and placed on girders "C," and, as a temporary footwalk had been constructed on the west side of the avenue, it will be seen that all structures were thus carried on girders "C."

All structures were put on the girders "C" before continuing the excavation on the sides of the avenue because, in case of a slide of rock, there would be less danger than to individual structures. The

Fig. 1.

Fig. 2.

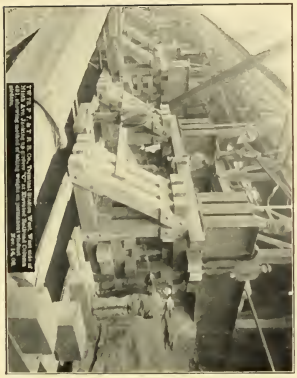


Fig. 3.

Fig. 4.

outside piers, on which the girders "C" rested, might even be lost, without affecting the stability of the structure, and posting could readily be done beneath these girders in case of necessity.

A very careful record of levels, taken on the elevated railway columns, was kept, observations being made during each jacking up and at least twice a week during the progress of the work. The columns were usually kept about $\frac{1}{2}$ in. high so as to allow for compression in the timber bents.

As a rule, no jacking of the elevated railway structure was done while trains were passing over, and trains were flagged during the operation. There was generally very little delay, as all jacking was done between 10.30 A. M. and 2.30 P. M., when the traffic was lightest, and frequently the jacking was done between trains, causing no delay whatever. Steel clamps were placed, three on the top and three on the bottom of each set of the girders "C," to bind them together and cause them to act as a unit.

All structures then being supported on girders "C," which were carried on four concrete piers resting on the central rock core, the excavation on the sides of the avenue was continued down to sub-grade and the east and west portions of the concrete north abutment were constructed. The central rock core was about 36 ft. wide on the top and 45 ft. wide on the bottom, and at the center of 32d Street it was about 42 ft. high.

It was the original intention to excavate a sufficient width of the sides of the avenue to erect six rows of the permanent steel viaduct, 5 ft. from center to center, and this was done on the south portion of the work. On the north portion, however, the rock was of poor quality, and it was thought best to excavate for only five rows at first, to erect the five rows of permanent steel and put the timber bents in place under the ends of the girders "C," in order to give them some support while the outside concrete piers were being removed and the excavation was being widened out to permit the erection of the sixth row. Additional raker braces were put in these bents temporarily, and were removed when the sixth row of steel had been erected. This is shown on Figs. 4 and 5.

Fig. 4, Plate XLVII, and Fig. 1, Plate XLVIII, show the structures supported on the central rock core and the excavation on the east side to permit of the erection of the permanent viaduct girders.

Fig. 1, Plate XLVIII, shows also the easterly portion of the concrete north abutment. Fig. 2, Plate XLVIII, shows five rows of the permanent viaduct girders erected on the east side of the work.

The excavation of the sides of the avenue having been completed, and six rows of permanent viaduct girders erected on both sides, timber bents, as shown on Figs. 2, 4, 5, and 6, were erected on this steel to support the ends of the girders "C" and carry the structure while the rock core was being excavated. Fig. 3, Plate XLVIII, shows the method of taking the weight on these bents. Four 80-ton jacks were used, and oak blocks were placed on the top of each jack to transmit pressure to a temporary oak cap under the girders "C" independent of the bents; all four of these jacks were operated simultaneously, and the girders "C" were lifted off the bents and clear of the concrete piers. Oak filling pieces were then inserted between the bents and the girders "C," so that when the jacks were released the girders "C" were clear of the concrete piers. Fig. 3, Plate XLVIII, shows that the girders have been lifted off the piers. Elevations were taken on each set of girders during each operation, and careful observations were made on the elevated railway columns. Where the rock was very close to these bents, the open space between the posts was filled with blocking so that there would be less danger of the bent shifting if struck by blasted materials. Fig. 3, Plate XLVIII, shows one of these bents filled with blocking.

All structures being carried on girders "C," which, in turn, were carried on the sides of the permanent viaduct, the central core was excavated. Fig. 4, Plate XLVIII, and Figs. 1, 2, 3, and 4, Plate XLIX, show various views of the work at this stage.

The central portion of the viaduct was then erected, and, using concrete piers and timber bents, all structures were placed on its deck. Fig. 3, Plate XLIX, shows the piers under the elevated railway columns prior to the removal of girders "C."

During the latter part of 1908 a 48-in. cast-iron water main was laid by the city on a cradle built by the Railroad Company on girders "C" on the east side of the avenue. This is part of the high-pressure system, and the location and elevation of this water main were taken into consideration when the underpinning was designed. This main, and the 48-in. cast-iron sewer bracketed to girders "C," are shown on Fig. 4, Plate XLVIII.

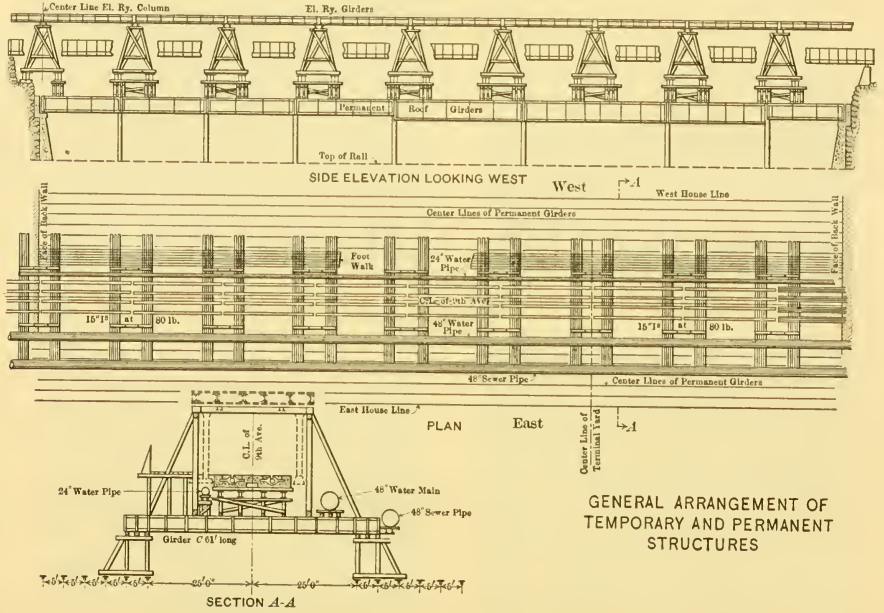

Center Line El. Ry. Column
El. Ry. Girders
Permanent Roof Girders
Top of Rail
SIDE ELEVATION LOOKING WEST
West
A
West House Line
Center Lines of Permanent Girders
Face of Back Wall
Foot Walk
24" Water Pipe
C.L. of 9th Ave.
48" Water Pipe
15"I@ at 80 lb.
48" Sewer Pipe
Center Lines of Permanent Girders
East House Line
PLAN
East
Center Line of Terminal Yard
A
C.L. of 9th Ave.
24" Water Pipe
48" Water Main
48" Sewer Pipe
Girder C 61' long
25'0"
25'0"
SECTION A-A
GENERAL ARRANGEMENT OF TEMPORARY AND PERMANENT STRUCTURES

FIG. 6.

Elevations had been taken on marks on the elevated railway columns between 30th and 34th Streets at the time the original surveys were made, in 1902, and these marks were used to test the level of the structure during the progress of the excavation.

At the extreme south end of the work the procedure was changed. The east side was excavated down to sub-grade, the east portion of the south abutment was constructed, and six rows of the permanent steel viaduct were erected. Very little excavation had been done on the west side of the avenue at the south end of the work, and it would have delayed the completion of the work to have waited for the excavation for and the construction of the west portion of the south abutment and the erection of the steel; therefore, instead of supporting the girders "C" on the central rock core, the east ends were taken up on the permanent viaduct girders, and the west ends were supported on a concrete pier on the rock. The central portion of the avenue was excavated in advance of the west portion. The permanent viaduct girders were put in place from east to west across the avenue, and the girders "C" were supported on the deck of the permanent viaduct approximately under the west elevated railway columns before the west portion of the avenue was excavated, the central portion of the south abutment having been constructed before the west portion. This procedure was adopted only at the north girders "C" at elevated railway column No. 488, the south set of girders "C" being on the rock immediately south of the south abutment. Figs. 2 and 4, Plate XLIX, and Fig. 2, Plate LII, show various stages of the work at the south end.

It was made a practice all through the work to transfer the weight of the structures very positively from one support to another by lifting them bodily by jacks, and putting in filler pieces before releasing the jacks, not trusting to wedging to transfer the loads. In fact, apart from the boxing-in of the surface railway concrete, no wedges whatever were used. This appears to have been a decided advantage, for, with the constant pounding of trains on the elevated railway and the jarring due to heavy trucks on the pavement blocks, it is very likely that wedging would have become loosened and displaced, whereas, with blocking, there was little or no tendency toward displacement due to vibration. Although the vibration of the structure, when a long length was supported on girders "C" resting on the permanent viaduct

Fig. 1.

Fig. 2.

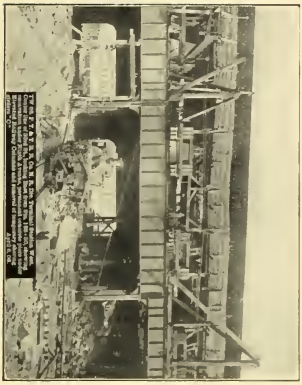


Fig. 3.

Fig. 4.

girders on the sides of the avenue, appeared to be considerable, not only vertically but transversely, very careful observation showed that the sag in the girder "C" due a live load of three elevated railway trains, one surface railway car, and one heavy truck, amounted to $\frac{1}{8}$ in. The sideway vibration did not amount to more than $\frac{1}{32}$ in. on either side of the normal position. More vibration was caused by heavy trucks and wagons going over the stone pavement than by the elevated railway trains or surface cars.

No blasting was done near the supports of the elevated railway structure while trains were passing over it, and occasionally trains were stopped during a heavy or uncertain blast. A watchman on the surface, day and night, and at first one and later two flagmen on the elevated railway structure, were on duty at all times, reporting to the Interborough Rapid Transit Company, by whom they were employed. Log mats and timber protection for the girders and the columns of the permanent viaduct were used, as shown by Figs. 1 and 4, Plate XLIX, during the excavation of the rock core, and timber was also used to protect the face of the completed portions of the concrete abutments.

In excavating the sides of the avenue, the rock broke better on the east than on the west side, where large seams developed and some slides occurred.

Abutments.—As shown on Fig. 7, the face of the north abutment has a batter of 2 in. to the foot, and the face of the south abutment has a variable batter, the base being on a grade and the bridge seat being level, and both maintaining a uniform distance from the center of the Terminal Yard. The back walls of the abutments were not built until the steel had been put in place.

No attempt was made to water-proof these abutments, but, in the rear of the wall, open spaces were left, about 6 ft. from center to center, which were connected with drain pipes at the base of and extending through the wall, for the purpose of carrying off any water that might develop in the rock. These drains were formed by building wooden boxes with the side toward the rock open and the joints in the boxes and against the rock plastered with mortar in advance of the wall. A hose was used to run water through these drains during the placing of the concrete, for the purpose of washing out any grout which might run into them. Each box was washed out at frequent

intervals, and there was no clogging of the drains whatever. This method of keeping the drains open was adopted and used successfully for the entire work. The abutments were built of concrete, and the mixture was 1 part of cement, 3 parts of sand, and 6 parts of broken stone.

The concrete was mixed in a No. 3 Ransome mixer, and was placed very wet. No facing mixture or facing diaphragms were used, but the stone was spaded away from the face of the wall as the concrete was laid. Chutes were used inside the form, if the concrete had to drop some distance. Work was continued day and night, without any intermission, from the time of commencement to the time of completion of each section.

The face of the concrete wall was rubbed and finished in a manner similar to that used on the walls between Ninth and Tenth Avenues, as described later.

Fig. 2, Plate LII, shows the east and central portions of the south abutment, completed and carrying the permanent viaduct, and the excavation completed for the west portion.

Work Between Ninth and Tenth Avenues.

General Description.—The work involved the excavation of about 5.4 acres, between the west house line of Ninth Avenue and the east house line of Tenth Avenue, to an average depth of about 50 ft., the construction of a stone masonry portal at Tenth Avenue leading to the River Tunnels, and the construction around the site of the concrete retaining and face walls.

The following estimated quantities appear in the contract: Excavation of rock in trenches, 3 400 cu. yd.; excavation of rock in pit, 377 000 cu. yd.; excavation of all materials except rock in trenches, 6 500 cu. yd.; excavation of all materials except rock in pit, 34 000 cu. yd.; concrete, 1:3:6, in retaining walls, 4 580 cu. yd.; concrete, 1:3:6, in face walls, 7 460 cu. yd.; concrete, 1:2:3, with $\frac{3}{4}$-in. stone, in face walls, 4 100 cu. yd.; stone masonry in portal, 247 cu. yd., etc., etc.

As previously stated, the contract price included the placing of all excavated material on scows at Pier 62, North River. Prior to this contract this pier had been used by the New York Contracting Company-Pennsylvania Terminal, for the disposal of excavated material

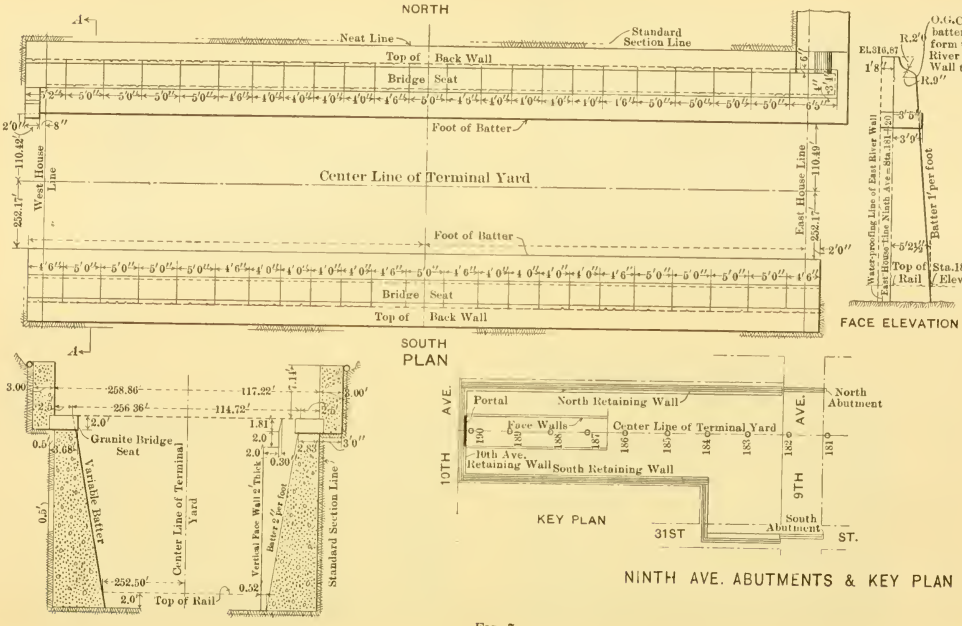

NORTH
Neat Line
Standard Section Line
Top of Back Wall
Bridge Seat
Foot of Batter
Center Line of Terminal Yard
West House Line
East House Line
Foot of Batter
Bridge Seat
Top of Back Wall
SOUTH
PLAN
O.G. Curve and batter to conform to East River design of Wall to North
Water-proofing Line of East River Wall
East House Line Ninth Ave. Sta. 181+20
Batter 1"per foot
Top of Rail
Sta. 181+14.79
Elev. 286.34
FACE ELEVATION
SECTION A-A
Granite Bridge Seat
Variable Batter
Center Line of Terminal Yard
Vertical Face Wall 2' Thick
Batter 2" per foot
Standard Section Line
Top of Rail
Portal
North Retaining Wall
Face Walls
Center Line of Terminal Yard
10th Ave. Retaining Wall
South Retaining Wall
North Abutment
South Abutment
10TH AVE.
9TH AVE.
31ST ST.
KEY PLAN
NINTH AVE. ABUTMENTS & KEY PLAN

FIG. 7.

from east of Ninth Avenue. In order to get the material to the pier, the contractor had excavated a cut under Ninth Avenue which came to the grade of 32d Street about midway between Ninth and Tenth Avenues, and a trestle was constructed from this point over Tenth Avenue and thence to the pier. Fig. 2, Plate XLVII, shows the east end of this cut, and Fig. 1, Plate L, shows the trestle, looking east from Tenth Avenue.

A 30-ton steam shovel was brought to the south side of the work, and commenced operating on July 9th, 1906. After working there about a month, the earth had been practically stripped off the rock, and the shovel was moved over to the north side where it excavated both earth and rock until August 10th, 1907.

At three points south of 32d Street and at one point north of 32d Street near Tenth Avenue, cuts were made in the rock to sub-grade, and from these cuts, together with the cuts on the west side of Ninth Avenue, all widening out was done and the excavation was completed. Fig. 1, Plate L, shows the excavation of the three cuts on the south side of 32d Street, the steam shovel operating on the north side of that street, and the material-disposal tracks and trestle. Fig. 3, Plate LII, shows the cuts joined up and the excavation along the south side practically completed.

On the north side of the work, between Stations 182 + 90 and 183 + 65, the rock was low, and provision had to be made for maintaining the yards to the north of the site. Therefore a rubble-masonry retaining wall was built, with the face about 2 ft. north of the face of the proposed concrete wall which was to be put in later. On the same side of the work, between Stations 188 + 24 and 188 + 46, the rock was exceedingly poor, and as a small frame house on the adjoining lot was considered to be in an unsafe condition, a rubble masonry retaining wall was built. As the building adjoining the south side of the work at Tenth Avenue was on an earth foundation, it was necessary to underpin it before the excavation could be done. The building was supported on needles, and rubble masonry was put in from the bottom of the old foundation to the rock. The foundation of 413 West 31st Street, immediately west of the Express Building site, was of very poor masonry, and it was necessary to rebuild it prior to taking out the adjoining excavation.

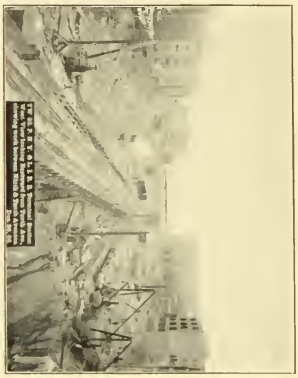


Fig. 1.

Fig. 2.

Fig. 3.

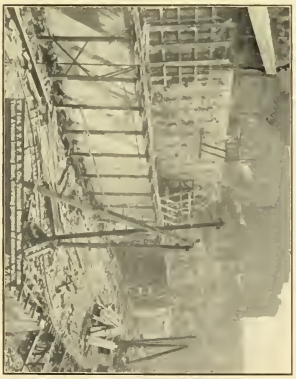


Fig. 4.

Along the north side, between Stations 186 + 50 and 187 + 50, the walls supporting the adjoining back yards were of poor quality and had to be renewed by the contractor before excavation could be done.

The excavated material was loaded by derricks on cars at the top of the excavation, these cars being on tracks having a direct connection with the disposal trestle, as shown by Fig. 1, Plate L. As soon as it could be done, derricks were placed at the bottom of the excavation; tracks were then laid out there, and the excavated material was loaded on cars at the bottom and hoisted by derricks to cars on the disposal trestle. A locomotive was lowered to the bottom of the excavation on August 25th, 1907, and a derrick started operating at the bottom on August 27th, 1907. The commencement of this work by derricks at the bottom is shown by Fig. 3, Plate LII. In general, the disposal tracks were maintained about on the center line of 31st Street until the excavation had been carried as close to them as possible, and on October 16th, 1907, they were shifted to the extreme north side of the work, as shown by Fig. 2, Plate L. A portion of the old trestle was left in place near Tenth Avenue, a derrick was erected thereon, and the tracks were used for cars to receive the excavated material hoisted from sub-grade. The disposal trestle was maintained in this position until such time as it would interfere with the excavation, and then the tracks were abandoned. This was done on November 11th, 1908. Fig. 3, Plate L, shows the finishing of the excavation on the north side of the work. On August 30th, 1908, a cut was made under Ninth Avenue at sub-grade, and cars could then be run from Seventh to Tenth Avenue at sub-grade. On October 24th, 1908, the connection with the disposal trestle east of Ninth Avenue was abandoned, and all excavated material was hoisted from sub-grade at Tenth Avenue by derricks.

As previously stated, the contractor was required to make complete disposal of all excavated material after January 1st, 1909, but was allowed the use of the pier until January 20th, 1909, after which date the materials were hoisted by derricks at Tenth Avenue, loaded on 2-horse trucks, and transported to the 30th Street pier, North River, where it was loaded on scows by two electric derricks. A considerable amount of the rock excavation was broken up and used for back-fill.

Earth Excavation.—Practically all the earth excavation, amounting to about 57 000 cu. yd., was done with steam shovels. The average quantity of earth excavated by a steam shovel per 10-hour shift was 180 cu. yd. This material was loaded on side-dump cars and taken to the disposal pier where it was dumped through chutes to the decks of scows. Inasmuch as the quantity of earth excavation was small, as compared with the rock, the earth was used principally for the first layer on the scows for padding, so that small stones might be dumped through the chutes without injuring the decks.

Rock Excavation.—As previously stated, the rock broke better on the south than on the north side, where there were several slides, and considerable excavation had to be taken out beyond the neat line required in the specifications. The worst slide occurred at midnight on July 3d, 1909, at about Station 188 + 50. The last blast, to complete the excavation to sub-grade at this point, had been fired in the afternoon of the same day, and the mucking was practically completed. Great care had been taken in excavating near this point, as it was evident that the rock was not of a very stable character, but, when the excavation had been completed, it was thought that the rock remaining in place would stand. The volume of material brought down by this slide amounted to about 200 cu. yd. The rock on the south side broke very well, and there were no slides of any consequence.

The drill holes were laid out by the blaster, and the general method of drilling for different classes of work was as follows: In breaking down, the holes were started about 8 ft. apart, on a slight batter, so that at the bottom they would be considerably less than 8 ft. apart. They were drilled about 10 ft. deep, and blasting logs were used, as it was necessary to load quite heavily in order to lift the material and start the cut. After the cut had been made, side holes were shot to widen out sufficiently to start another cut.

After a side cut about 20 ft. deep had been made, the side holes were drilled 20 ft. deep, and the holes were loaded and tamped for the full 20-ft. cut. Under the terms of the specifications, the contractor was required to complete the excavation on the sides by drilling broaching holes.

The maximum length of drill steel was about 20 ft., and, where the excavation plane of broaching was more than 20 ft. in depth, the contractor was permitted to start the holes back of the broaching line, in

order to allow for setting up the drills on the second lift. A distance of about 8 in. was usually allowed for setting up a drill. The broaching line was painted on the surface of the rock in advance of the drilling, and the batter of the drill was tested with a specially designed hand-level in which the bubble came to a central position when the face of the level was on the required batter. Holes were also drilled in front of this broaching line, and, when the excavation had been taken out to within about 6 ft. in front of it, the holes immediately in front were loaded, and also about every third one of the broaching holes, and, unless the rock was very bad, it usually broke sharply at the broaching line. Occasionally, the broaching holes which were not loaded were filled with sand, which gave rather better results than leaving them open.

In the steam-shovel work on the east side of Ninth Avenue, spring holes were used. They were formed by drilling a 20-ft. hole and exploding at the bottom of it, without tamping, two or three sticks of dynamite, and repeating this process with heavier charges until there had been formed at the bottom of the hole a large cavity which would hold from 100 to 200 lb. of dynamite. Face holes and breast holes were also drilled, and it was possible by this method to drill and break up a cut 20 ft. deep and 15 ft. thick. The only place where spring holes were used on this work was on the east side of Ninth Avenue, where the heavy cutting was sometimes extended beyond the east house line.

From the best records obtainable, the average progress in drilling was about 33 lin. ft. per 8-hour shift. The average number of cubic yards of excavation per drill shift was 13.9, and the average amount of drilling per cubic yard of excavation was 2.4 ft.; this covered more than 27 000 drill shifts.

The dynamite was practically all 60%, and the average excavation per pound of dynamite was 2.2 cu. yd. The contractor employed an inspector of batteries and fuses, who, using an instrument for that purpose, tested the wiring of each blast prior to firing, in order to discover any short circuits, and thus prevent the danger of leaving unexploded dynamite in the holes.

The average quantity of excavation per derrick shift of 10 hours, covering 7 400 shifts, 87% of the excavation being rock, was 50 cu. yd., and the average force per shift, including only foreman and laborers, was 13 men. It was found that a derrick operating at the top of a

20-ft. cut would handle about 40 cu. yd. per shift, whereas, if operating at the bottom of the cut, it would handle about 60 cu. yd. per shift. The elevator derricks at Tenth Avenue were very efficient, and each could take care of the material from four derricks at the bottom, hoisting 250 cu. yd. per shift a height of 60 ft.

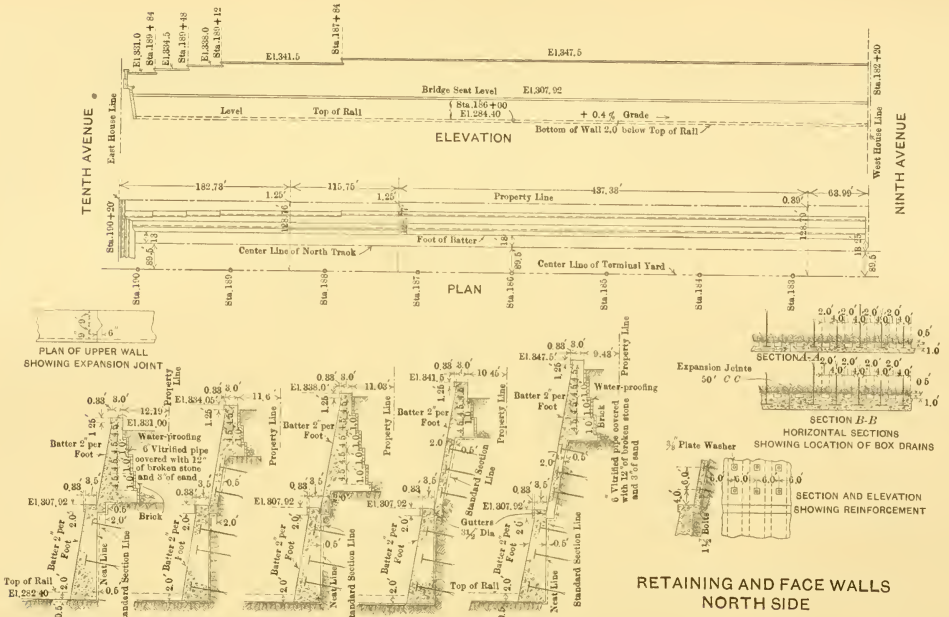
Concrete Retaining and Face Walls.—It was essential to have the greatest space possible at the bottom of the excavation, and, inasmuch as the yard was to be left open, it was necessary to provide some facing for the rock on the sides in order to prevent disintegration, due to exposure, and give a finished appearance to the work. Above the rock surface a retaining wall of gravity section was designed, the top being slightly higher than the yards of the adjoining properties. The face wall was designed to be as thin as possible, in order to allow the maximum space for tracks.

The excavation, therefore, was laid out so that the back of the retaining wall would not encroach on the adjoining property, but would practically coincide with the property line at positions of maximum depth.

The batter on the face of the wall was 2 in. per ft., and a bridge seat 3½ ft. wide was formed at an elevation of 22 ft., minimum clearance, above the top of the rail. This bridge seat was made level. The maximum height of the south wall is 49 ft., and of the north wall 65 ft.

The face walls were classed as "Upper Face Walls," extending from the base of the retaining wall to the bridge seat, and as "Lower Face Walls," extending from the bridge seat to the base of the wall. The general design is shown on Fig. 8.

In considering the design of the face wall it was felt that, the wall being so thin, ample provision should be made to prevent any accumulation of water and consequent pressure back of the wall; therefore, no attempt was made to water-proof it, but provision was made to carry off any water which might appear in the rock. Box drains, 2 ft. wide and 6 ft. from center to center, were placed against the rock, so that, there being but 4 ft. between the drains, and the wall having a minimum thickness of 2 ft., any water in the rock would not have to go more than 2 ft. to reach a drain, and would probably pass along the face of the rock to a drain rather than through 2 ft. of concrete. These drains were connected with pipes leading through the wall at its base.



RETAINING AND FACE WALLS
NORTH SIDE

FIG. 8.

These box drains occurred so frequently, and decreased the section of the wall so materially, that it was thought desirable to tie the wall to the rock. This was done by drilling into the rock holes from 6 to 15 ft. in depth, and grouting into each hole a 1¼-in. rod having a split end and a steel wedge. The outer end of each rod was fitted with a 12 by 12 by ½-in. plate and a nut, and extended into the wall, thus tying the concrete securely to the rock. The drains being 6 ft. from center to center, the tie-rods were placed midway between them, and 6 ft., from center to center, vertically and horizontally. Fig. 8 shows the arrangement of these rods and drains. Around the Express Building site, just west of Ninth Avenue, on the south side of the work, the bridge seat was omitted, and the face wall was designed 2 ft. thick from top to bottom. The batter on the 31st Street wall was made variable, the top and bottom being constant distances from the center line and on different grades.

The retaining walls were water-proofed with three layers of felt and coal-tar pitch, which was protected by 4 in. of brick masonry. A 6-in. vitrified drain pipe was laid along the back of the wall, with the joints open on the lower half, and this was covered with 1 ft. of broken stone and sand before any back-fill was placed on it.

The arrangement of the drains was as follows: The 6-in. drain back of the retaining wall was connected with one of the box drains in the rear of the face wall by a cast-iron pipe or wooden box every 24 ft., and this ran through the base of the retaining wall. Midway between these pipes, a connection was made at the bridge seat between the drain in the rear of the face wall and the gutter formed at the rear of the bridge seat to carry off rain-water coming down the face of the wall above. All the box drains, except those connected with the drains back of the retaining wall, were sealed at the elevation of the base of the retaining wall, as noted previously.

The specifications required vitrified pipe to be laid through the retaining wall, but, owing to the difficulty of holding the short lengths of pipe in place during the laying of wet concrete, they were dispensed with, and either iron pipes or wooden boxes were used.

Tie-Rods.—When the excavation on the sides had been completed, movable drilling platforms were erected, as shown by Fig. 4, Plate L. The holes were drilled on a pitch of 2 in. per ft. with the horizontal. The depths of the holes were decided by the engineer, and

were on the basis of a minimum depth of 5 ft. in perfect rock; the character of the rock, therefore, and the presence of seams, determined the depths of the holes. Each hole was partly filled with grout, and the rod, with the steel wedge in the split end, was inserted and driven with a sledge so that the wedge, striking the bottom of the hole first, would cause the split end of the rod to open. Each hole was then entirely filled with neat cement grout.

Box Drains.—Various methods of forming the box drains were considered, such as using half-tile drains, or a metal form, or a collapsible form which could be withdrawn, but it was finally decided to build boxes in which the side toward the rock was open and the joints in the boxes and against the rock were plastered with cement mortar. These boxes were left in place. Fig. 1, Plate LI, shows the tie-rods and box drains in place, and holes being cut near the bottom of the drains for the pipes leading through the wall.

Forms.—Fig. 1, Plate LI, shows the form used on the south side of the work. The materials were of good quality, and the form, which was about 50 ft. long, was used to build twelve sections, or about 600 ft. of wall. The form was tied in at the top and bottom by cables attached to rods drilled into the rock, and it was thought that, with the trusses to stiffen the middle section of the form, it would not be necessary to use raker braces against it. This would have been desirable, as the placing of the raker braces took considerable time. It was found, however, that the form was not sufficiently rigid, as it bulged at the middle section and could not be held by the trusses. Two or three sets of raker braces, about 12 ft. apart, were used, and in addition, rods with turnbuckles were placed through the form and fastened to the tie-rods, and thus the form was held in place successfully. On the forms built later, the trusses were omitted, and raker braces, about every 6 ft., were used. The rods which screwed into the turnbuckles were removed before the form was moved. The photograph, Fig. 4, Plate LII, was taken inside the concrete form for the lower face wall on the north side, and shows the drains leading through the wall, the turnbuckles attached to the tie-rods, the cables attached to rods in the rock, and the braces to keep the form from coming in; these braces, of course, were removed as the concrete came up. The form was built low and wedged up into position. After a section of concrete had set sufficiently, the wedges were knocked out, the form was lowered and

moved from the wall, and was then moved along the lowest waling piece by block and tackle to its new position.

Fig. 4, Plate L, shows the forms used on the north side of the work.

A section, 1 ft. square, at the top of the bridge seat of the lower face wall, was left out, so that the bottom of the form for the upper face wall could be braced against it. The top of this form was tied by cables attached to rods in the rock and by rods with turnbuckles running from back to front of the form; braces were also put in from the back of the retaining wall form to the walls of buildings along the property lines, when this could be done. The middle section of the form was held by rods with turnbuckles which passed through the form and were fastened to each of the tie-rods drilled into the rock, as was also done in the case of the lower face wall. It was generally possible to hold the form to true position in this manner, but occasionally it had a tendency to bulge; when this occurred, the rods leading through the form and fastened to the tie-rods were tightened up, the placing of the concrete was slowed up, and no serious bulging occurred.

Bulkheads at the ends of the sections were built of rough planking securely braced to the rock, except that a planed board was laid up against the face of the form to make a straight joint. At the end of each section a V was formed, as shown by Fig. 1, Plate LI. At all corners, a "return," or portion of the wall running at right angles, was built, and no section of wall was stopped at a corner.

Filling Forms of Lower Face Walls.—A temporary trestle was erected above the elevation of the bridge seat, and a track, leading from the mixer to the form to be filled, was laid on it. At the commencement of each section a layer of mortar (1 part of cement to 2½ parts of sand) was deposited on the bottom. A 1:3:6 mixture of concrete was used; it was run from the mixer into dump-cars and deposited in the form through chutes, three of which were provided for each 50-ft. section, the average length. The concrete was mixed wet, and was not rammed; the stone was spaded back from the face, and no facing mixture or facing diaphragms were used. Work on each section was continued day and night without any intermission from the time of commencement to the time of completion. At frequent intervals the box drains were washed out thoroughly with a hose, in order to prevent them from clogging up with grout.

Fig. 1.

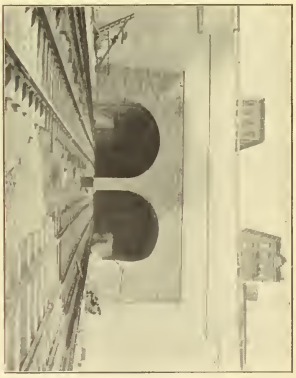


Fig. 2.

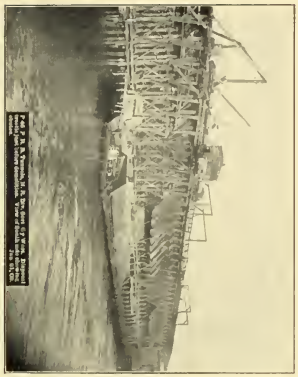


Fig. 3.

Fig. 4.

In the first few sections of wall, the form was filled to within 1 in. of the top of the bridge seat and allowed to set for about 2 hours; it was then finished to the proper elevation with a plaster of 1 part of cement to 1 part of sand. This did not prove satisfactory, as there were indications of checking and cracking, and, later, the form was filled to the required elevation and the surface floated. The form was allowed to remain in place for from 18 to 24 hours, depending on the weather. In most cases, immediately after the form had been moved, a scaffold was erected against the face of the wall, and the face was wet and thoroughly rubbed, first with a wooden float and then with a cement brick, until the surface was smooth and uniform.

The section 1 ft. square at the top of the bridge seat, which was left out in order to brace the bottom of the form for the upper face wall, was filled in after the walls had been completed. The old concrete was very thoroughly cleaned before the new concrete was placed on it, and a gutter was formed at the rear connecting with the box drains back of the wall to carry off rain-water coming down the face of the upper walls.

In hot weather the walls were thoroughly wetted down several times a day for several days after the form had been removed.

Upper Face and Retaining Wall.—In cases where the top of the retaining wall was at a higher elevation than the mixer, it was necessary to raise the concrete in a bucket with a derrick, and dump it into cars on the trestle above the top of the coping. Concrete was deposited through chutes, as in the lower face wall, continuously from the bottom of the face wall to the top of the retaining wall. At the commencement of each section of the retaining wall a layer of mortar was put on the rock. A 1:2:3 mixture of concrete was used in the face wall, and a 1:3:6 mixture in the retaining wall.

As the face walls were so thin, the number of batches of concrete per hour was reduced, for the form filled so rapidly that the concrete, before it set, exerted an excessive pressure against the form, and this tended to make it bulge. The proper rate at which to place the concrete behind a form 50 ft. long, with a wall 2 ft. thick, was found to be about fifteen ½-yd. batches per hour.

Cracks in Walls and Longitudinal Reinforcement.—Before the concrete walls were started, the contractor suggested using forms 100 ft.

long and building the walls in sections of that length; it was decided, however, to limit the length to 50 ft.

The south walls, in sections approximately 50 ft. long, were built first, starting at Tenth Avenue and extending for about 500 ft. Soon after the forms were removed, irregular cracks appeared in the walls between the joints in practically every section. It was thought that these cracks might be due to the wall being very thin and being held at the back by the tie-rods; there was also quite a material change in the section of the wall at each drainage box. Although it was admitted that these cracks would have no effect on the stability of the wall, it was thought that, for appearance sake, it would be desirable to prevent or control them, if possible. The first method suggested was to shorten the sections to 25 ft., which would give an expansion and contraction joint every 25 ft., it being thought that sections of this length would not crack between the joints. This, however, was not considered desirable. An effort was then made to prevent cracks in a section of wall, about 46 ft. long, on the south side, by using longitudinal reinforcement. In the lower and upper face walls, $\frac{3}{4}$-in. square twisted steel rods were placed longitudinally about 4 in. in from the face and about 1 ft. 4 in. apart vertically. The sections of these walls were finished on April 10th, and May 5th, 1909, respectively. At present there are no indications of cracks in these sections, and they are practically the only ones in the south walls which do not show irregular cracks.

It was decided, however, that, inasmuch as the cracks did not affect the stability of the walls, the increased cost of thus reinforcing the remaining walls was not warranted. An effort to control the cracks was made by placing corrugated-iron diaphragms in the form, dividing each 50-ft. section into three parts. The diaphragms were 1 ft. wide, and were placed with the outer edge 1 in. in from the face of the wall, but in the copings they were omitted. The purpose of these diaphragms was to provide weak sections in the walls, so that if there was any tendency to crack it would occur along the line of the diaphragms. Corrugated iron was used for the diaphragms instead of sheet iron as it was more easily maintained in a vertical position. The general arrangement of the diaphragms is shown on Fig. 4, Plate LII. The results obtained by using diaphragms have been quite satisfactory, and cracks approximately straight and vertical have usually appeared

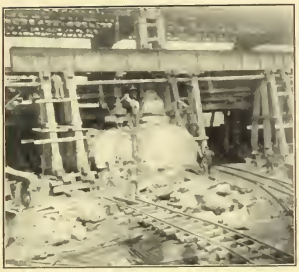


FIG. 1.—GIRDERS UNDER 9TH AVENUE ELEVATED RAILROAD.

FIG. 2.

FIG. 3.

FIG. 4.

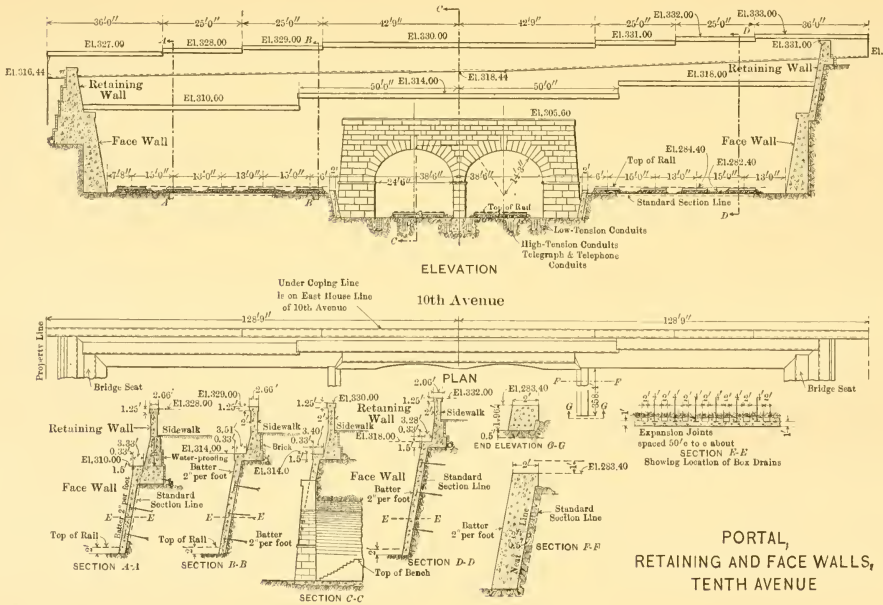
opposite the diaphragms soon after the forms were removed. Diaphragms were used on all the remaining walls, with the exception of those between Stations 187 + 07 and 188 + 83 on the north side, where the rock was of poor character and bad slides had occurred. Between these points, in order to strengthen the wall, twisted steel rods, 1 in. square, were placed longitudinally, 6 in. in from the face of the wall and 2 ft. apart vertically, between Elevations 295 and 335.

Tenth Avenue Portal.—The design of the Tenth Avenue Portal is shown on Fig. 9. The stone selected came from the Millstone Granite Company's Quarries, Millstone Point, Conn., and is a close-grained granite. Fig. 2, Plate LI, shows the completed portal.

Practically all the stone cutting was done at the quarry, but certain stones in each course were sent long and were cut on the ground, in order to make proper closures. Drains were left behind the portal around the back of each arch, leading down to the bottom, and through the concrete base at each side of the portal and in the central core-wall; all these drains have been discharging water.

Power-House.—The old church at No. 236 West 34th Street, between Seventh and Eighth Avenues, was turned over to the New York Contracting Company-Pennsylvania Terminal for a power-house to supply compressed air for use on the Terminal Station work between Seventh and Ninth Avenues and the work below sub-grade as well as that on the Terminal Station-West. Four straight-line compressors and one cross-compound Corliss compressor were installed, the steam being supplied by three Stirling boilers. Three electrically-driven air compressors, using current at 6 600 volts, were also installed, and the total capacity of the power-house was about 19 000 cu. ft. of free air per minute compressed to 90 lb. per sq. in.

Disposal Pier.—The disposal pier (old No. 62 and new No. 72), at the foot of West 32d Street, North River, was leased by the Pennsylvania Railroad Company. The entire pier, with the exception of the piles, was taken down, and the piles which would be in the path of the proposed tunnel were withdrawn prior to the building of the tunnels and the construction of the pier for disposal purposes. Subsequent to the driving of the tunnels there was a considerable settlement in the pier, especially noticeable at the telphers, and finally these had to be abandoned on this account. Fig. 3, Plate LI, shows the chutes through which the earth was dumped on the decks of the scows



PORTAL, RETAINING AND FACE WALLS, TENTH AVENUE

FIG. 9.

to form a padding on which to dump the heavier rock. Fig. 4, Plate LI, shows the derricks at the end of the pier. These were used, not only for loading heavy stones and skips, but also with a clam-shell bucket for bringing in broken stone and sand for use in the work. Large quantities of pipe, conduits, brick, etc., were also brought to this pier for use on the work.

Organization of Engineering Force in Field.

The design and execution of the work were under the direction of Charles M. Jacobs, M. Am. Soc. C. E., Chief Engineer, and James Forgie, M. Am. Soc. C. E., Chief Assistant Engineer. The writer acted as Resident Engineer.

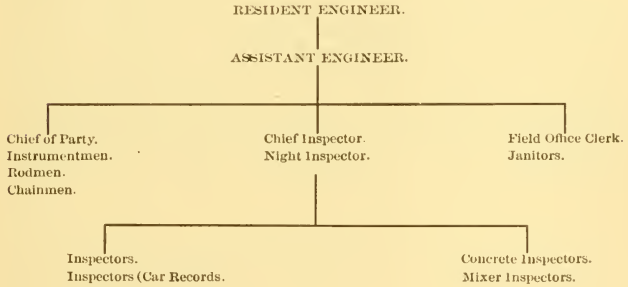


Fig. 10.

The general organization of the engineering force in the field is shown by the diagram, Fig. 10.

The position of Assistant Engineer, in responsible charge of Construction and Records, has been filled in turn by Messrs. A. W. Gill, N. C. McNeil, Jun. Am. Soc. C. E., and W. S. Greene, Assoc. M. Am. Soc. C. E.

Messrs. A. P. Combes and T. B. Brogan have acted as Chief Inspector and Night Inspector, respectively, in charge of outside work during the entire carrying out of the contract.

Base lines had been established on Ninth and Tenth Avenues for the Terminal work east of Ninth Avenue and for the Tunnel work

west of Tenth Avenue, and these lines, together with bench-marks similarly established, were used in laying out the Terminal Station-West work.

Prior to the commencement of the work, elevations were taken on the surface at 10-ft. intervals, and elevations of the rock surface were taken on these points as the rock was uncovered. Cross-sections were made and used in computing the progress and final estimates.

Very careful records were kept of labor, materials, derrick performances, steam-shovel performances, quantity of dynamite used, etc., and, in addition, a diary was kept giving a description of the work and materials used each day; various tables and diagrams were also prepared.

A daily report was sent to the Chief Office showing the quantities of excavation removed and concrete built, the force in the field, the plant at work, etc., during the previous day. At the end of each month a description of the work done during that month, with quantities, force of men employed, percentages of work done, etc., was sent to the Chief Office. Two diagrams, showing cross-sections and contours of the excavation done and the progress of the concrete walls, were also sent.

Cost Account.

From the records of labor and material obtained in the field, and from estimated charges for administration and power, an estimate was made of the cost to the contractor for doing various classes of work. It was necessary to estimate the administration and power charges, as the contractor's organization and power-house were also controlling and supplying power to the Terminal Station work east of Ninth Avenue and also the work below sub-grade. The labor and material charges in the field were placed directly against the class of work on which they were used and the administration and general charges (which included superintendence, lighting, etc.) were apportioned to the various classes of work in proportion to the value of the labor done.

Statistics.

The total weight of the structural steel used during the underpinning of Ninth Avenue was 1 475 000 lb.

The total weight supported during the work under Ninth Avenue was about 5 000 tons.

The average daily traffic over the Ninth Avenue Elevated Railway was 90 000 passengers, and, during the progress of the excavation and underpinning, about 100 000 000 passengers were carried over that structure.

The total excavation was 521 000 cu. yd., of which 87% was solid rock.

The average drill performance was about 33 lin. ft. per 8-hour shift.

The average number of cubic yards of excavation per drill shift was 13.9.

The average number of feet of drilling per cubic yard of excavation was about 2.4.

The average excavation per pound of dynamite was 2.2 cu. yd.

The average amount of excavation per derrick shift of ten hours, 87% of the excavation being rock, was 50 cu. yd.

The average derrick force per shift, including only foreman and laborers, was 13 men.

The salaries of the engineering staff in the field and the expenses of equipping and maintaining the field office amounted to 2.8% of the cost of the work executed, 2.7% being for engineering salaries alone.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1157

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE SITE OF THE TERMINAL STATION.*

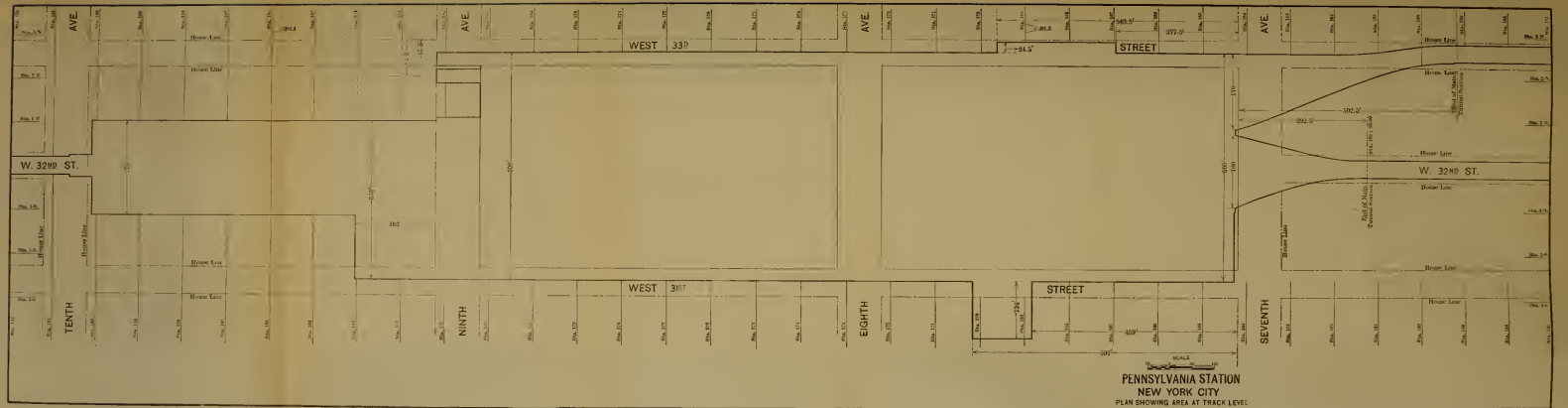
By George C. Clarke, M. Am. Soc. C. E.

The purpose of this paper is to describe the preliminary work for and the preparation of that portion of the site for the Terminal Station in Manhattan, of the New York Tunnel Extension of the Pennsylvania Railroad, which was constructed under the direction of the Chief Engineer of the East River Division, including the disposal of material excavated from all parts of the Terminal construction and the tunnels on the East River Division.

As outlined in the paper by Brigadier-General Charles W. Raymond, M. Am. Soc. C. E., Chairman of the Board of Engineers, the track yard of the station, Plate LIII, extends from the east line of Tenth Avenue eastward to points in 32d and 33d Streets, respectively, 292 and 502 ft. east of the west line of Seventh Avenue. The width of the available area at track level at Tenth Avenue is 213 ft., continuing at this width to within 182 ft. of the west line of Ninth Avenue, where, by an offset toward the south, it is increased to 355 ft. This width is held to a point 5 ft. east of the east line of Ninth Avenue, where, by an offset toward the north, it is increased to 509 ft., which width continues to the west line of Seventh Avenue, where it divides into two fan-shaped areas. The north area has a width of about 170

* Presented at the meeting of May 4th, 1910.

PLATE LIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1107.
CLARKE ON
PENNSYLVANIA R. R. TUNNELS: TERMINAL STATION SITE.



PENNSYLVANIA STATION
NEW YORK CITY
PLAN SHOWING AREA AT TRACK LEVEL

ft. and the south one, 160 ft., at the house line, each area tapering gradually to the width of the standard three-track tunnel at the east ends, noted above in 33d and 32d Streets. Additional track room for four tail-tracks is gained by the construction of two double-track tunnels under Ninth Avenue at 33d Street, their center lines being parallel to the street and 45.5 and 84.5 ft. distant, respectively, from the north house line. An additional width of 24.5 ft. is occupied on the north from 277.5 ft. to 543.5 ft. west of the west line of Seventh Avenue, where the buildings on the north side of 33d Street have been torn down and the enclosing wall set back in anticipation of a future outlet to 34th Street; and on the south, from 459 ft. to 597 ft. west of the west line of Seventh Avenue a rectangular offset of 124 ft. encloses the area occupied by the Service Building. The total area above outlined is the space occupied at track level, and amounts to 28 acres, of which the portion west of the east house line of Ninth Avenue and south of a line 107.3 ft. south of the south line of 33d Street is a part of the North River Division, and was constructed under the direction of the engineers of that Division; the fan-shaped areas east of the west house line of Seventh Avenue were constructed under the direction of the Chief Engineer of Electric Traction and Terminal Station Construction.

In June, 1903, when the writer's connection with the work began, the preliminary surveys had been completed and the location and extent of the Terminal track area had been fixed, in so far as the city blocks to be occupied were concerned. This contemplated area, however, did not include the portion between Ninth and Tenth Avenues, that being added subsequently. The elevation of the track level had also been fixed by the requirement in the agreement with the City that no part of the permanent structure should approach within 19 ft. of the surface under any avenue or under any street except within the Terminal area. The nearest approach of the tracks to the surface is at a point 320 ft. east of Eighth Avenue, where the top of the rail is 40 ft. below the 31st Street curb line.

Wash-Borings.

The general plan of enclosing the area in retaining walls having been adopted, wash-borings were taken, for the purpose of determining the best location for the walls, the depth of rock, and the nature of

the material overlying it. These borings were made along both curb lines of Seventh Avenue, the east curb line of Ninth Avenue, the north curb line of 33d Street, and the south curb line of 31st Street. The borings, as a rule, were taken at intervals of approximately 100 ft., some deviation in these intervals being made in order to prevent injury to water, gas, and sewer connections, and, if the elevation of the surface of the rock, as determined by one of these borings, corresponded fairly well with the borings on either side of it, no intermediate borings were taken. When a discrepancy appeared, a boring was taken midway between the two non-corresponding ones, and if the information obtained from the intermediate boring failed to account for the discrepancy, others were taken at the quarter points of the original 100-ft. interval.

The dotted lines on Fig. 1 show the profiles of the surface of the rock underlying 31st and 33d Streets, on the line of the borings, constructed from the elevations obtained by them; the solid lines show the profiles of the actual surface of the rock as found when uncovered. It will be noted that, except in three cases, Borings 313, 328, and 333, the two profiles correspond very closely at the points where the borings were made, but they differ widely between those points, a variation of 5 ft. being common; there is a variation of 14 ft. between Borings 324 and 327, and between Nos. 337 and 340; and of 12 ft. between Nos. 333 and 335, and between Nos. 312 and 313, while an extreme variation of 17 ft. is shown between Nos. 303 and 305. At each of the points where the variation is great the interval between borings is the full 100 ft., and it is quite apparent that, if a definite idea is to be obtained of the elevation of the surface of the rock in Manhattan, borings must be taken at shorter intervals.

The necessary width of trench for the construction of the retaining walls was determined by the elevation of the rock, as shown by the borings, and only in the case of the dip between Borings 303 and 305 did the variation lead to any difficulty. The trench at that point had to be widened after rock was reached. This depression corresponded very closely in location to that of one arm of the creek shown on General Viele's map of 1865,* the bed of that stream, or one in ap-

* Reproduced as Plate IX in the paper by Mr. Noble.

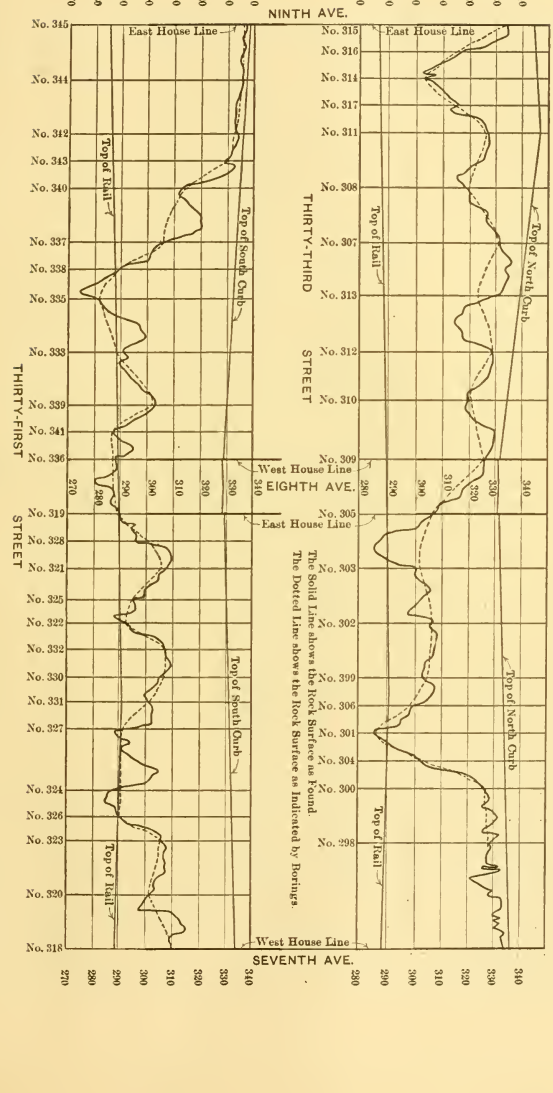

PROFILE OF ROCK SURFACES IN THIRTY-FIRST AND THIRTY-THIRD STREETS, BETWEEN SEVENTH AND NINTH AVENUES.
NINTH AVE.
SEVENTH AVE.
EIGHTH AVE.
THIRTY-FIRST STREET
THIRTY-THIRD STREET
East House Line
West House Line
Top of Rail
Top of South Curb
Top of North Curb
The Solid Line shows the Rock Surface as Found.
The Dotted Line shows the Rock Surface as Indicated by Borings.

FIG. 1.

proximately the same location, being clearly marked across the excavation by smoothly-worn rock and well-rounded boulders. The original stream, however, seemed to have turned in a westerly direction under 31st Street to Eighth Avenue instead of crossing, as shown on General Viele's map.

Sewers.

The arrangement of the sewers in the streets in the vicinity of the Terminal Site, previous to the beginning of the construction, and the drainage area tributary to those sewers, is shown by Fig. 2. The main sewer for this district was in Eighth Avenue, and was a 6-ft. circular brick conduit within the Terminal area. The sewers leading to it from the west, in 31st, 32d, and 33d Streets, were elliptical, 3 by 2 ft., and egg-shaped, 4 ft. by 2 ft. 8 in., although in no case did they drain more than one block, and they were on a heavy grade. Draining into Eighth Avenue from the east, the one on 31st Street was 4 ft. by 2 ft. 8 in., egg-shaped, and drained a length of two blocks, and those on 32d and 33d Streets were circular, 4 ft. in diameter, and drained the territory for three blocks, or as far east as Fifth Avenue. There were no sewers in Seventh Avenue within the Terminal area, except small vitrified pipes, each less than 200 ft. in length.

It was desirable that the size and number of the sewers in the streets and avenues surrounding the Terminal should be reduced to a minimum, on account of the difficulty of caring for them during construction and also to reduce the probability of sewage leaking into the underground portion of the work after its completion. With this in view, the plan was adopted of building an intercepting sewer down Seventh Avenue from north of 33d Street to the 30th Street sewer, which, being a 4-ft. circular conduit, was sufficiently large to carry all the sewage coming from east of Seventh Avenue and south of 34th Street. It was decided to build this sewer of cast iron where it crossed the proposed construction work, and also to replace with cast iron the brick sewers on 31st, 32d, and 33d Streets from Seventh Avenue to a point east of the west end of the standard tunnel section, and also the sewer on Eighth Avenue from the north side of 33d Street to the south side of 31st Street. This arrangement permitted: first, the removal of the sewer in 32d Street between Seventh and Eighth Avenues, which was necessary, as that street was to be excavated; second, the reduction of the sewer in Eighth Avenue from a

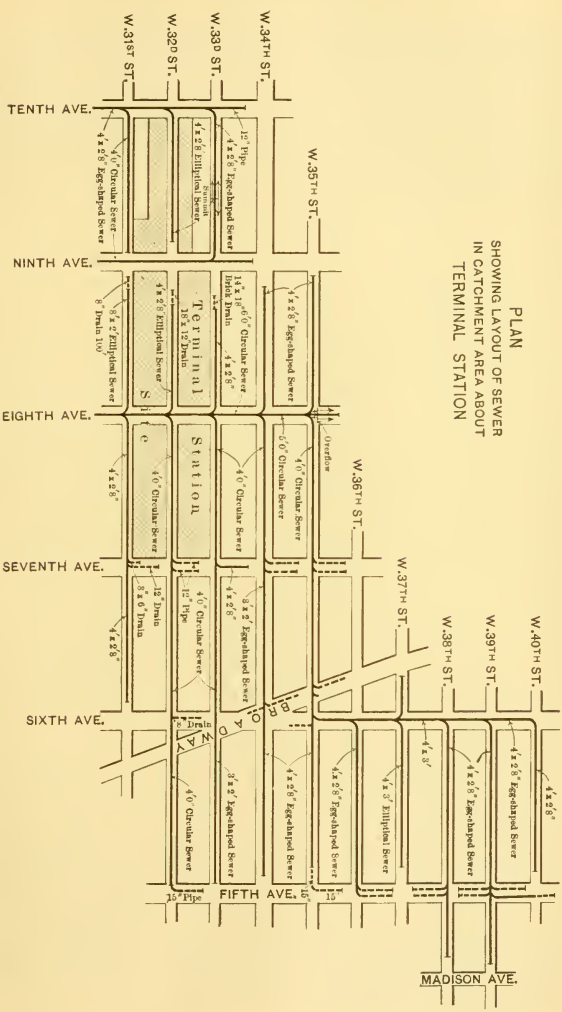

PLAN
SHOWING LAYOUT OF SEWER
IN CATCHMENT AREA ABOUT
TERMINAL STATION
W.31ST ST.
W.32D ST.
W.33D ST.
W.34TH ST.
W.35TH ST.
W.36TH ST.
W.37TH ST.
W.38TH ST.
W.39TH ST.
W.40TH ST.
TENTH AVE.
NINTH AVE.
EIGHTH AVE.
SEVENTH AVE.
SIXTH AVE.
FIFTH AVE.
MADISON AVE.
BROADWAY
Site
Terminal
Station
Summit
Overflow
12" Pipe
4'x 2'8" Egg-shaped Sewer
4'x 2'8" Elliptical Sewer
4'0" Circular Sewer
8"x 2'8" Elliptical Sewer
8" Drain 100'
18"x 12" Drain
14"x 18" Brick Drain
6'0" Circular Sewer
5'0" Circular Sewer
12" Drain
8"x 6" Drain
3'x 2' Egg-shaped Sewer
4'x 3' Elliptical Sewer
4'x 3'
15" Pipe
15"

FIG. 2

6-ft. to a 5-ft. circular conduit; and, third, assuming that the sewage and drainage from the Terminal would be pumped directly to the sewers in the avenues, the reduction of the sewers in 31st and 33d Streets, from Seventh to Ninth Avenue, to 15-in. vitrified pipes, except west of the Service Building in 31st Street, to accommodate which section, a larger sewer was required. The sewer in 32d Street, from Ninth to Eighth Avenue, of course, could be dispensed with in any arrangement, as all the area tributary to it was to be excavated.

Gas and Water Mains.

A rearrangement of the gas pipes in the three streets crossing the Terminal site was necessary. These pipes were of two classes: trunk mains and service mains. Fortunately, there were but two trunk mains in the three streets, one a 20-in. in 31st Street from east of Seventh Avenue to Ninth Avenue, the other a 16-in. in 32d Street from east of Seventh Avenue to Eighth Avenue. The 20-in. main was relaid from Seventh Avenue and 31st Street down Seventh Avenue to 30th Street and through that street to Ninth Avenue. The 16-in. main was relaid from Seventh Avenue and 32d Street north to 34th Street and through that street to Eighth Avenue. The service mains in 32d Street were no longer required, and were taken up and not replaced. The houses on 31st and 33d Streets were provided with service by two 6-in. wrought-iron mains back of the retaining walls in each street, that location being chosen to avoid damage by gas drip to the water-proofing of the street bridges. As the permanent structures under the avenues were not to approach the surface nearer than 19 ft., only slight rearrangements, sufficient to permit the new sewers and water lines to be laid, were necessary.

There were no large water mains to be cared for, in fact, those in the streets were too small for ample fire protection, being only 6 in. in diameter. The main in 32d Street was taken up and not replaced, and those on 31st and 33d Streets were replaced by 12-in. pipes laid back of the retaining walls. No changes were necessary in the mains in the avenues, but, before approving the rearrangement for the streets, the Department of Water Supply, Gas and Electricity added a 48-in. main in Eighth Avenue to be laid as a part of this construction, the pipe being supplied by the City.

Location and Design of Retaining Walls.

The plans, from the earliest stages, contemplated founding the retaining wall on the surface of the rock, where of suitable quality, and afterward excavating the rock in front of the toe of the wall to sub-grade. This plan was definitely adopted soon after the borings were completed, on account of the great danger of blasting out large quantities of rock in timbered trenches close to buildings founded on soft material, and also to avoid the additional cost and delay that would have been caused by carrying the walls to sub-grade. The retaining walls in Seventh Avenue, south of the viaduct, and in Ninth Avenue, north of the viaduct, were not governed by the same conditions as in the streets. The dip and quality of the rock at both points required that the walls be carried to sub-grade, and they are, in fact, face walls; the Ninth Avenue wall, in particular, having little thrust to sustain, is very light.

The results aimed at in the design and location of the retaining walls in 31st and 33d Streets were:

First.—A perfectly stable wall under all conditions that might reasonably be expected;

Second.—As much room as possible at the elevation of the top of rail;

Third.—The least necessary interference with adjoining property during construction; and,

Fourth.—The most economical wall that would fulfill the other conditions.

As stated in the paper by Alfred Noble, Past-President, Am. Soc. C. E., the third stipulation required the relinquishing of a portion of the space under these streets granted by the City, but it was finally decided not to approach the south house line of 31st Street with the back of the walls nearer than 9 ft., while on 33d Street the extreme position of the back was fixed at the north line, as there were no buildings, except those belonging to the Railroad Company, on the house line at the low points in the rock.

The assumptions made in designing the wall were as follows:

First.—Weight of concrete, 140 lb. per cu. ft.

Second.—Weight of material from the surface of the ground to a depth of 12 ft. (which was shown by tests made in bore-holes

to be the elevation of the ground-water surface), 100 lb. per cu. ft.; and angle of repose, 30 degrees. The distance of 12 ft. below the surface was the depth of the inverts of the sewers, which undoubtedly drained the ground above them, thus accounting for the standing of the ground-water in planes practically parallel with the surface.

Third.—Weight of buildings back of wall neglected, as that of the present type will about equal the cellars filled with material at 100 lb. per cu. ft., and if large buildings are erected in the future they will undoubtedly be carried to rock.

Fourth.—Reaction from superstructure, live and dead load, 20 000 lb. per lin. ft. of wall.

Fifth.—Weight of materials below the 12-ft. line, 124 lb. per cu. ft., ascertained as follows: The material was considered as weighing 165 lb. per cu. ft. in the solid, and having 40% of voids filled with water at 62.5 lb. per cu. ft., the resulting weight being $\left(165 \times \frac{60}{100}\right) + \left(62.5 \times \frac{40}{100}\right) = 124$ lb. per cu. ft.

Various angles of repose were used for this material in the investigation, and it was finally decided that 30° was the greatest angle that could be expected, whereas the worst condition that could be anticipated was that the sand and water would act separately and give a pressure as follows:

Hydraulic pressure from liquid weighing 62.5 lb. per cu. ft. plus pressure from sand with angle of repose at 30° and weight as follows:

Weight of 1 cu. ft. in air $= 165 \times \frac{60}{100} = 99$ lb.

Weight of water displaced by 1 cu. ft. $= \frac{60}{100} \times 62.5$ lb. $= 37.5$ lb.

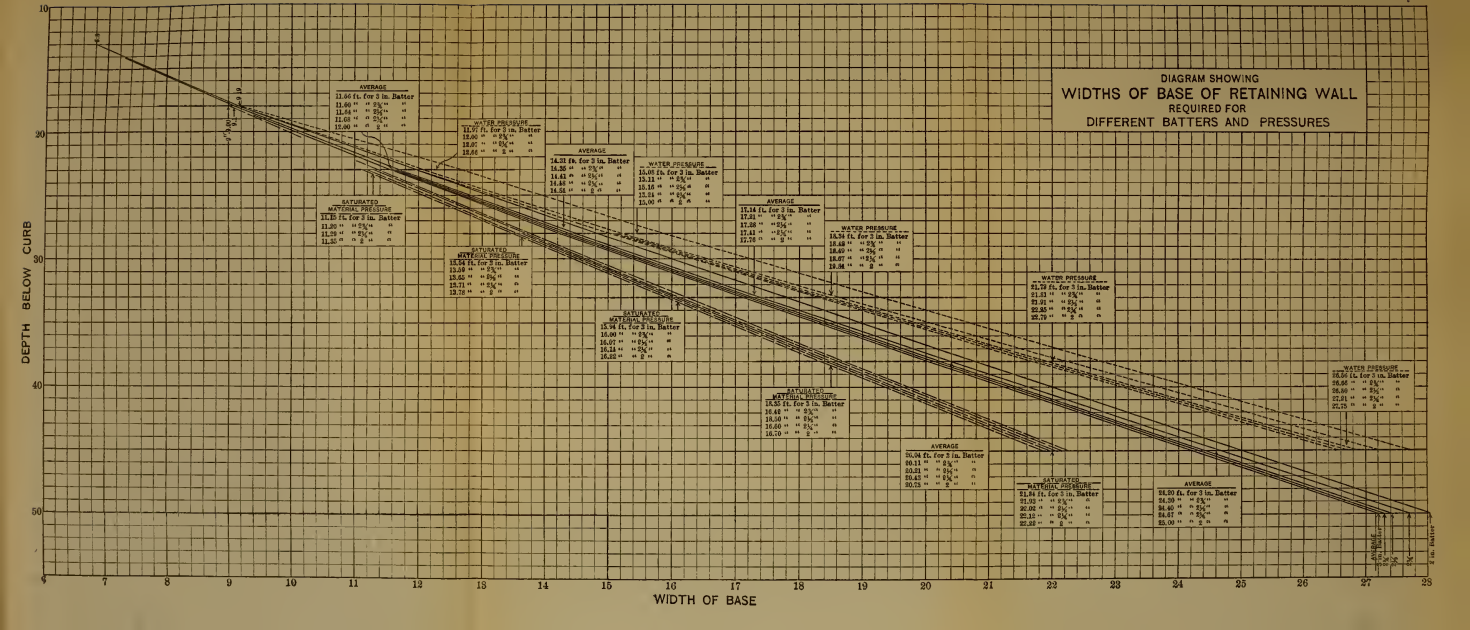
Weight in water, therefore $= 61.5$ lb. per cu. ft.

These combined weights, of course, are equal to the weight of the combined material in the previous assumption.

Sixth.—The usual requirement that the resultant of both horizontal and vertical forces should, at all points, fall within the middle third of the wall, or, in other words, that there should be no tension in the concrete.

With these assumptions, investigation was made of walls with various batters and differently designed backs. This investigation de-

PLATE LIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1157.
CLARKE ON
PENNSYLVANIA R. R. TUNNELS: TERMINAL STATION SITE.



veloped the fact that the reaction from the superstructure was so great that, for economy, both in first cost and space occupied, the batter must be sufficient to cause that reaction to fall within or very close to the middle third. Nothing could have been gained by having that reaction fall back of the front of the middle third, as the wall was required to be stable against the full pressure before the superstructure was erected, and in case it should ever be removed; or, to state the matter more clearly, the reaction from the superstructure was so great in comparison to the weight of the wall, that, if it fell in front of the resultant of all the other forces, the width of base required would be greatly increased to make the wall stable after the superstructure was erected; whereas, if the reaction from the superstructure fell back of the resultant of all the other forces, the width of base could not be correspondingly decreased without danger of the wall being overturned before the superstructure was erected. The least batter that would answer those conditions was found to be 2 in. per ft.

For convenience in designing, and economy in constructing, the steelwork, the faces of the bridge seat and of the backwall were laid parallel to the center line of the Terminal, and in elevation on line parallel to the top of the curb and as near to it as the economical depth of steel would permit, without bringing the finished construction above the plane fixed in the ordinance. As there is a variation of 13 ft. in the elevation of the top of the curb of 31st Street above the top of rail and a variation of 18 ft. in 33d Street, a uniform batter, with the top parallel to the center line, would produce a toe varying in distance from it and from the other constructions. It was decided, therefore, for the sake of appearance, to make the face of the wall (or wall produced) at the top of rail parallel to the center line, and to vary the batter accordingly, using the 2-in. batter previously mentioned as the minimum. This gave a maximum batter of 3 in. per ft. The variation is so gradual that it is unnoticeable, and is not sufficient to introduce any complications in construction.

The wall was designed with a stepped back, primarily to allow the water-proofing and brick protection to be held in position more readily. The first step was put at 13 ft. below the surface of the ground. This gave a vertical back above that point for a 3-in. battered face, and a slightly battered back for sections having a less batter in front. Below that point a step was added for each 5 ft. of depth

to the elevation of the top of rail, or to the foundation of the wall if above that elevation. As the horizontal distance of the heel of the wall, at its greatest width, from its face at the top of rail would determine the effective room to be occupied by the wall, it was determined to make the back vertical below the top of rail and gain the necessary increase in width below that point by making a heavy batter on the face.

The type of wall having been thus determined, calculations were made of the width of base required for each ¼-in. batter from 2 to 3 in., inclusive, first for a depth of 13 ft. below the top of the curb and then for each 5 ft. below that elevation, to a depth corresponding to the distance between the top of the curb and the top of the rail at the point of greatest variation. These widths of wall were determined for the two pressures previously decided on, and curves were then plotted showing the thickness of wall required for each batter calculated and for each pressure. They are shown on Plate LIV. The curves in broken lines represent the widths required for saturated material, and the curves in dotted lines for hydraulic pressure. Mean curves were then drawn between each broken and its corresponding dotted curve. These are shown in solid lines, and represent the widths of wall which were used in the construction. Typical sections of the wall and pipes back of it are shown on Fig. 3.

The extreme positions of the back of the wall on the two streets having been determined, as previously stated, the width of base required at those points fixed the toe of the wall at the top of rail as 254.5 ft. south of the center line of the Terminal in 31st Street, and 258.5 ft. north of the center line in 33d Street.

Contracts.

The construction was done under the following contracts:

1.—The principal contract, dated June 21st, 1904, was with the New York Contracting and Trucking Company, later assigned by that company to the New York Contracting Company-Pennsylvania Terminal, for the performance of the following works:

(*a*).—The excavation for and construction of a retaining wall in Seventh Avenue, 31st Street, Ninth Avenue, and 33d Street.

(*b*).—Excavation over the area enclosed by the retaining wall.

(*c*).—The building of sewers and the laying of water and gas pipes.

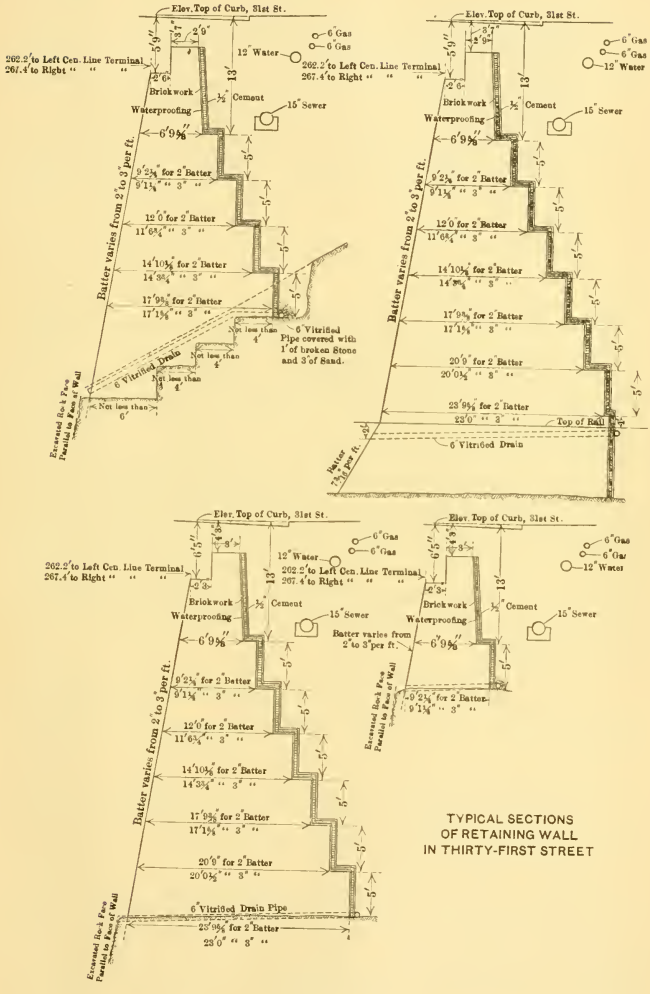

Elev. Top of Curb, 31st St.
6" Gas
6" Gas
12" Water
262.2' to Left Cen. Line Terminal
267.4' to Right " " "
Brickwork
½" Cement
Waterproofing
15" Sewer
6'9⅝"
Batter varies from 2' to 3' per ft.
9'2¾" for 2" Batter
9'1¼" " 3" "
12'0" for 2" Batter
11'6¾" " 3" "
14'10⅛" for 2" Batter
14'3¾" " 3" "
17'9⅝" for 2" Batter
17'1⅝" " 3" "
20'9" for 2" Batter
20'0½" " 3" "
23'9⅝" for 2" Batter
23'0" " 3" "
Top of Rail
6" Vitrified Drain
Not less than 4'
6" Vitrified Pipe covered with 1' of broken Stone and 3" of Sand.
Not less than 6'
Excavated Rock Face Parallel to Face of Wall
Water 2% per ft.
TYPICAL SECTIONS OF RETAINING WALL IN THIRTY-FIRST STREET

FIG. 3.

(*d*).—The building of a timber trestle to support the surface of Eighth Avenue between the south side of 31st Street and the north side of 33d Street, and also the surface of 31st and 33d Streets between Seventh and Ninth Avenues. This refers to the trestles left in place on the completion of the work.

(*e*).—The building of a trestle and bridging from a point near the west side of Tenth Avenue on the south side of 32d Street, westward to the outer end of Pier No. 62, at the foot of 32d Street.

2.—The second contract, dated February 10th, 1905, was with the New York Contracting Company-Pennsylvania Terminal, for the excavation for and construction of retaining walls for the Manhattan Terminal Power Station, and the excavation of the area thus enclosed.

3.—The third contract, dated October 2d, 1907, was with the New York Contracting Company-Pennsylvania Terminal, for the construction of two twin tunnels under Ninth Avenue, and other work incidental thereto.

Sewers and gas mains laid outside the area covered by the foregoing contracts were constructed under the following agreements:

An agreement, dated August 9th, 1904, between the New York Contracting Company-Pennsylvania Terminal, and the New Amsterdam Gas Company, for a 20-in. gas main from Seventh Avenue and 31st Street to 30th Street, and thence to Ninth Avenue, the New Amsterdam Gas Company being remunerated for the cost by the Tunnel Company.

A contract, dated August 24th, 1904, with the New York Contracting Company-Pennsylvania Terminal, for the construction of sewers in Seventh Avenue and in 32d and 33d Streets east of Seventh Avenue.

A contract, dated November 24th, 1908, with the New York Contracting Company-Pennsylvania Terminal, for the construction of a 16-in. gas main from Seventh Avenue and 32d Street to 34th Street, and thence to Eighth Avenue.

All these contracts required that the excavated material be delivered on board scows to be furnished by the company at the pier at the foot of 32d Street, North River. These scows were furnished and the material was disposed of from that point by Henry Steers, Incorporated, under a contract, dated August 9th, 1904, which called for

the transportation to and placing of all material so delivered in the Pennsylvania Railroad Company's freight terminal at Greenville, N. Y.

The disposal of the excavated material was one of the principal features of the work, and, under the above contract, material from those portions of the Terminal site east of Seventh Avenue and west of Ninth Avenue, and from all substructures work, was disposed of, as well as from the constructions herein described. The problem differed from that presented by the usual foundation excavations in New York City in magnitude only, and the methods were not unusual, but were adaptations of the usual ones to exceptionally large work.

Piers and Trestle for Disposal.

The most rapid and economical handling of all excavated material to scows was made possible by the Tunnel Company procuring from the New York Central and Hudson River Railroad Company the pier at the foot of 32d Street, North River, known in the earlier stages of the work as Pier No. 62, but subsequently changed to Pier No. 72, and thus referred to in this paper. This pier was occupied by a freight-shed used by the New York Central Railroad Company, under a long-term lease from the City, and that Company had to make numerous changes in their tracks and adjoining piers before No. 72 could be turned over; the contract for the excavation, therefore, required the contractor to procure any piers needed previous to and in addition to it. Under this clause of the agreement, the contractor procured one-half of the pier at 35th Street, North River, which was used for the disposal of all material excavated previous to May 22d, 1905, on which date Pier No. 72 was first put in service.

As the type of plant the contractor would elect to use could not be determined, previous to the letting of the contract, a general plan for Pier No. 72 and the trestle approach, suitable for either trains or wagons, was attached to the contract, and the details were worked out afterward. The method adopted was by train, and a two-track approach to the pier was provided. Beginning on the east side of Ninth Avenue, at the south line of 32d Street, at an elevation of 20 ft. below the surface, crossing under Ninth Avenue and to the center line of 32d Street, it rose on a 1.5% grade in open cut to the surface of 32d Street at a point 500 ft. west of Tenth Avenue, from which point it rose above the surface of the street on a timber trestle to Tenth Avenue, which

was crossed overhead. West of Tenth Avenue the line changed by a reverse curve to the south sidewalk of 32d Street, and continued on a timber trestle, practically level, to the New York Central Yard tracks near Eleventh Avenue. These tracks and Eleventh Avenue were crossed overhead on a through-truss, steel bridge, and a column-and-girder construction on which the two tracks separated to a distance of 29 ft. between center lines, so as to bring them directly over the posts of special timber bents which spanned the two house tracks of the New York Central south-bound freight shed, which the trestle here paralleled. This position was held to a point 25 ft. west of the east house line of Twelfth Avenue, where, by a system of cross-overs and turn-outs, access was had from either track to six tracks on the pier. Four of these were on upper decks, two on the north and two on the south edge of the pier, at an elevation of 41 ft. above mean high tide, to carry earth and small rock to chutes from which it was dumped into barges. The other two tracks proceeded by a 5.3% grade down the center of the pier to the lower deck where, at a distance of 540 ft. from the bulkhead, and beyond the upper deck construction, they diverged into six, two on the north and two on the south edge of the pier for standing tracks to serve derricks, and two down the center for shifting purposes. A siding to the north of the two running tracks just west of the bottom of the incline served a bank of eight electric telphers. The arrangement of the pier is shown by Fig. 4.

The trestle east of the steel structure at Eleventh Avenue had simple four-post bents, as shown by Bent *"A,"* on Fig. 5, all posts being vertical, to save room at the street level; the outside posts and the caps and sills were of 12 by 12-in. timber; the intermediate posts were of 8 by 12-in. timber; and single or double decks of 3 by 8-in. bracing were used, depending on the height of the bents. These bents were framed on the ground in position and raised by hand. West of Tenth Avenue, the sills of the bents rested on four 12 by 12-in. longitudinal timbers, each spanning two bays and breaking joints, for convenience in supporting the trestle while the tunnels were constructed in open cut beneath. These bents were placed 12 ft. on centers, with one 8 by 16-in. stringer under each rail, and one 6 by 16-in. jack-stringer supporting the overhang of the floor on either side.

The bents along the New York Central freight shed had but two posts of 12 by 14-in. yellow pine varying from 26 ft. to 31 ft. 9 in.

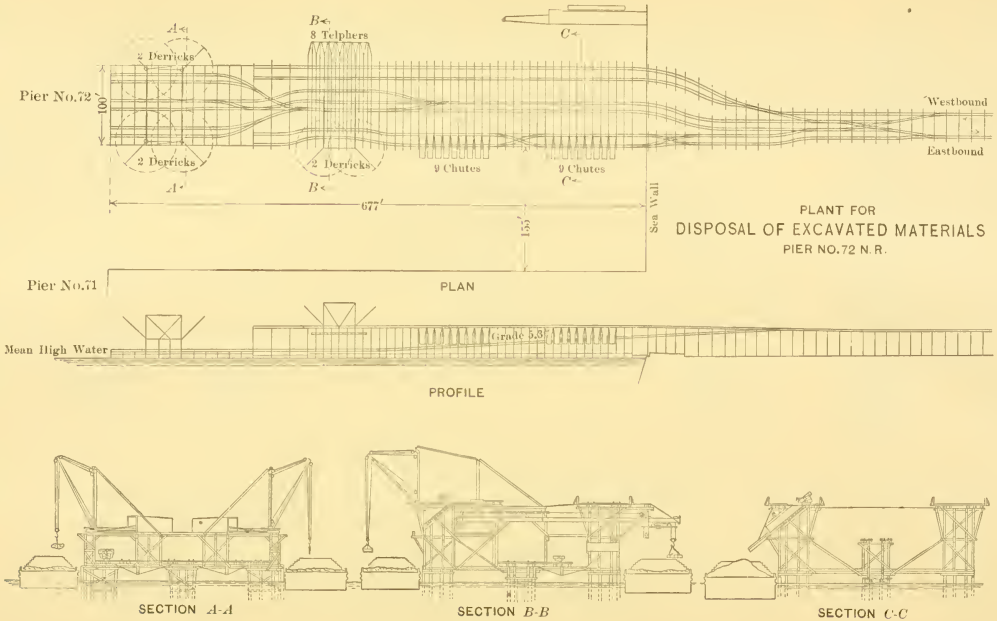

A
2 Derricks
B
8 Telphers
C
Pier No.72
100'
2 Derricks
2 Derricks
9 Chutes
9 Chutes
Westbound
Eastbound
A
B
C
677'
153'
Sea Wall
PLANT FOR
DISPOSAL OF EXCAVATED MATERIALS
PIER NO.72 N.R.
Pier No.71
PLAN
Mean High Water
Grade 5.3%
PROFILE
SECTION A-A
SECTION B-B
SECTION C-C

FIG. 4.

from center to center; they had double caps of 12 by 14-in. yellow pine on edge, no bottom sills or bracing, and the vibration and wind pressure were taken care of by the top bracing and anchorage, as shown by Bent *"G,"* on Fig. 6.

The method of erection was as follows: An excavation was made on the line of each post, 4 ft. deep and from 4 to 5 ft. square, depending on whether it was for a single or reinforced post; 6 in. of concrete was placed in the bottom, and on this were laid, at right angles to the center of the trench, three 8 by 12-in. timbers varying in length with the excavation from 3 to 4 ft. To these timbers was drifted one 12 by 12-in. timber of the same length as those in the bottom row, but at right angles to them. Elevations were then taken on top of the 12 by 12-in. timber, and the bent was framed complete and of correct height. The framing was done south of the line of the trestle and west of the freight-house. The framed bents were picked up by a small two-boom traveler carrying two double-drum, electric, hoisting engines, and run forward into position. A hole had previously been made in the metal gutter and canopy of the freight-house, by an experienced roofer, and in the freight platform underneath, and, as soon as the bent had been dropped into position, it was firmly drifted to the foot-blocks, previously described, and the excavation made for them was filled with concrete well rammed about the blocks and rounded off 6 in. above the surface of the ground. Secure flashings, in two sections, were then made about the posts to cover the holes made in the gutter and roof, the bottom sections being firmly soldered to the roof or gutter, and the top sections, which lapped over the bottom and cleared them 2 in. in all directions, were firmly nailed to the posts and the joints leaded. This arrangement allowed the bents to move slightly, and at the same time made the roof and gutter water-tight. These bents were placed 16 ft. on centers to correspond with the spacing of the doors of the freight shed.

Under the cross-overs near Eleventh Avenue, where the tracks had to be supported in different positions on the caps, and could no longer be kept over the posts, the caps were trussed and the posts were reinforced, as shown on Bents *"J," "H"* and *"K,"* Fig. 5.

The trusses for the through bridge over the tracks were erected on Sunday, April 16th. The two trusses, one 122 ft. and the other 165 ft. 8 in. from center to center of end posts, had been assembled

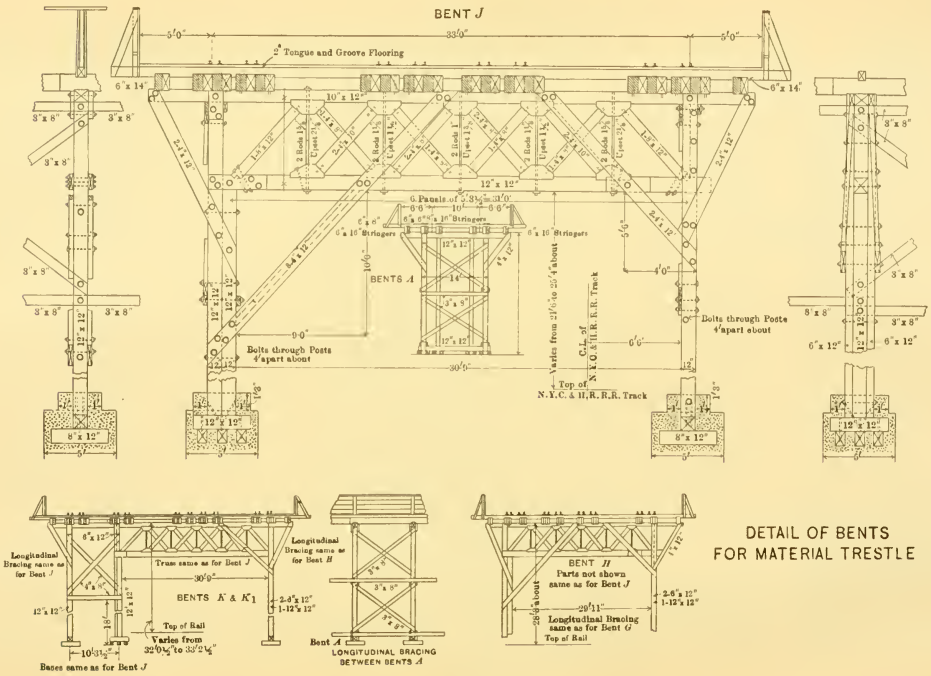
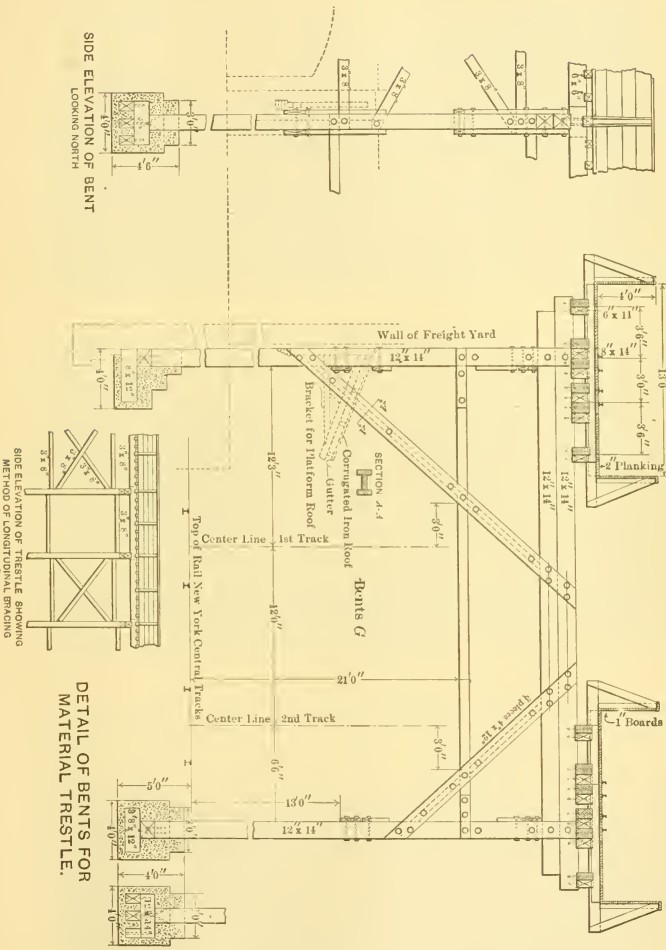

BENT J
2" Tongue and Groove Flooring
6"x 14"
3"x 8"
10"x 12"
12"x 12"
6 Panels of 5'-3½"=31'-0"
6'-6"
10'-0"
6'-6"
6"x 16" Stringers
BENTS A
14"
12"x 12"
8"x 12"
Bolts through Posts 4'apart about
9'-0"
30'-0"
Varies from 21'-6" to 25'-6" about
Top of N.Y.C. & H.R.R.R. Track
G.L. of N.Y.C. & H.R.R.R. Track
5'-0"
4'-0"
0'-0"
BENTS K & K1
Longitudinal Bracing same as for Bent J
Truss same as for Bent J
30'-0"
2-8"x 12"
1-12"x 12"
Top of Rail
Varies from 32'-0½" to 33'-2¼"
Bases same as for Bent J
Bent A
Longitudinal Bracing same as for Bent H
LONGITUDINAL BRACING BETWEEN BENTS A
BENT H
Parts not shown same as for Bent J
29'-11"
Longitudinal Bracing same as for Bent G
25'-6" about
DETAIL OF BENTS FOR MATERIAL TRESTLE

FIG. 5.

and riveted, lying flat on cribwork a few feet above the ground, south of the permanent position and between the New York Central tracks and Eleventh Avenue. On the date stated, the contractor, having been given permission to block the Central's tracks from 5 A. M. to 9 P. M., erected a large steel gin pole just south of the correct position of the center of the north truss, which was then dragged, from the place where it had been assembled, across the railroad tracks until the center of the bottom chord was vertically under its true position, the truss still lying flat and about at right angles to the center line of the bridge. Chains were made fast to the top chord at the middle panel of the truss, which was then turned up to a vertical plane, raised to its permanent position, and guyed. The gin pole was then shifted and the operation repeated with the longer truss, after which, half of the floor beams and a part of the top laterals were bolted in position and the guys were removed, the bridge being thus erected without the use of falsework of any kind. During the lifting there was no sag in either truss that could be noticed by the eye. Fig. 1, Plate LV, shows the bridge erected, with the exception of the tight timber fence.

Pier No. 72 is directly over the North River Tunnels. When it was turned over by the New York Central Railroad Company, the contractor for the construction of those tunnels tore down the shed and removed the deck and such piles as were in the path of the tubes. This left standing the four northernmost, the four southernmost and two centers rows of piles for the entire length of the pier. An additional row of piles was then driven on either side of the two center rows, and battered so that at the elevation of the tunnels they would be close to the center rows and leave as much clear space as possible. The pier, therefore, was constructed of three independent lines of four-post bents, which, however, rested on sills which were continuous throughout the width of the pier, as shown by Figs. 2 and 3, Plate LV.

The bents for the upper floors of the pier were double-decked, with 12 by 12-in. posts, sills, intermediate and top caps, and 3 by 8-in. longitudinal and cross-bracing. The bents for the incline were similar, except that those below 16 ft. in height were of single-deck construction. The spacing of the bents varied from 9 ft. 6 in. to 12 ft., except the three outer bays, which had a span of 23 ft., all to agree with the position of the pile bents. The double-deck construction extended for



DETAIL OF BENTS FOR MATERIAL TRESTLE.

Fig. 6.

the full length of the original pier. A single-deck extension, of full width and 180 ft. in length, was subsequently built for the accommodation of four derricks for handling building material and large rock. The piles for this extension were driven in three sets of four rows each, similar to those in the old portion of the pier, except that the bents were driven with a uniform spacing of 15 ft. between centers. The three sets of bents were topped separately with 12 by 12-in. caps and 12 by 12-in. dock stringers; they were braced with both cross and longitudinal low-water bracing, and were tied together by a continuous 12 by 12-in. timber over the dock stringers and 12 by 12-in. packing pieces from stringer to stringer, each of these ties being supported in the center of the span over the tunnels by two 2-in. hog rods, Section "*A-A*," Fig. 4.

The south side of the upper deck of the pier carried three sets of nine hoppers, each set covering 90 ft., a little less than the full length between bulkheads of the largest deck scows, with 70 ft. clear between sets, to allow for the length of a scow outside of the bulkhead and to permit the free movement of boats. Each hopper occupied the full space between two bents, and, as the caps were topped by strips of timber of triangular section, with a width of 12 in. on the base and a height of 6 in., protected by a 6 by 6-in. steel angle, each set of hoppers presented 90 lin. ft. of continuous dumping room. The bottoms of the hoppers, set at an angle of 45°, were formed by 12 by 12-in. timbers laid longitudinally, running continuously throughout each set, and covered by 3-in. planking. The partitions were formed with 4-in. planks securely spiked to uprights from the floor of the hoppers to the caps; these partitions narrowed toward the front and bottom so as to fit inside the chutes. Each hopper was lined on the bottom and sides with $\frac{1}{4}$-in. steel plates, and the bottoms were subsequently armored with 2 by 1-in. square bars laid 3 in. on centers and bolted through the 12 by 12-in. flooring of the hoppers. The chutes, extending from the bottom of the hoppers, were 20 ft. long and 7 ft. wide, in the clear; they were formed entirely of steel plates, channels, and angles, and were supported from the upper deck of the pier by chains; their lower ends were 17 ft. above mean high tide and 14 ft. 6 in. from the string piece of the pier. The hoppers and chutes are shown by Fig. 1, Plate LVI.

A length of 150 ft. of the north side of the pier was for the use of the contractor for the North River tunnels; it was equipped with a set

FIG. 1.—MATERIAL TRESTLE OVER N. Y. C. & H. R. R. R. CO.'S TRACKS.

FIG. 2.—MATERIAL TRESTLE UNDER CONSTRUCTION ON PIER NO. 72, NORTH RIVER, SHOWING CLEAR WATER OVER TUNNEL LOCATION.

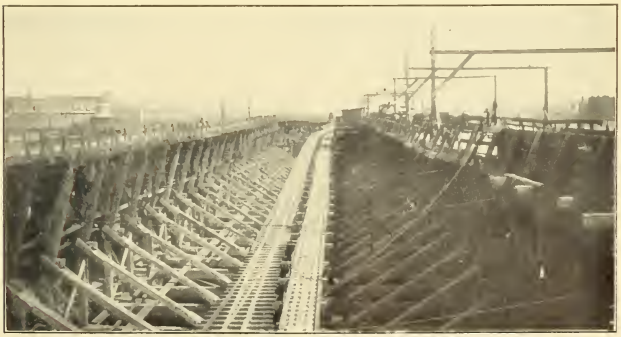


FIG. 3.—PIER NO. 72, NORTH RIVER, SHOWING INCLINE AS RECONSTRUCTED FOR LOCOMOTIVES.

of nine chutes similar to those for the south side; they were used but little, and were finally removed to make room for a cableway for unloading sand and crushed stone.

At the foot of the incline there was a bank of eight telphers running on rails securely bolted to the tops of 20-in. I-beams, which were hung from stringers resting on the upper caps. The beams were erected in pairs, each pair being securely braced together and to the trestle posts to prevent swaying. Each telpher occupied the space between two bents, about 10 ft., so that the entire bank commanded a length of 80 ft., which was approximately the length of a rock scow between bulkheads. All supports for the telphers were provided as a part of the trestle, but the machines themselves were a part of the contractor's plant.

Four derricks were erected on the extension, two on the north and two on the south edge of the pier, supported on bents at a sufficient elevation above the floor to clear a locomotive.

After most of the earth had been excavated, the out-bound set of hoppers on the south side of the pier was removed, and two derricks were erected in their place and used for unloading sand, crushed stone, and other building material.

Plant.

As the use of the 35th Street pier for the disposal of material required that the mode of transportation should be by dump-wagons drawn by horses, the plant in use by the contractor during that period necessarily differed in many respects from what it was later, when Pier No. 72 was available. Therefore, the nature of the plant during each period will be stated. The plant for each period will be divided into five classes:

1.—Central Plant:
   (*a*) Power-Generating Plant.
   (*b*) Repair Shops.
2.—Retaining-Wall Plant.
3.—Pit-Excavating Plant.
4.—Transportation Plant.
5.—Dock Plant.

Horse-and-Truck Period: July 11th, 1904, to May 22d, 1905.

1.—Central Plant.

(*a*).—*Power-Generating Plant.*—The contractor's first central generating plant was established in a 35 by 85-ft. steel-framed building covered with corrugated iron, the long side being parallel to Ninth Avenue and 15 ft. from the east house line, and the north end 43 ft. south of the south house line of 32d Street. The foundations for the building and machinery were of concrete, resting on bed-rock, the floor being 20 ft. below the level of the Ninth Avenue curb. The south end of the building was the boiler-room and the north end the compressor-room, the two being separated by a partition. Coal was delivered into a large bin, between the boiler-house and Ninth Avenue, its top being level with the street surface, and its base level with the boiler-room floor.

At the end of the horse-and-truck period the plant consisted of:

Two Rand, straight-line compressors, 24 by 30 in., having a capacity of 1 400 cu. ft. of free air per min. when operating at 86 rev. per min. and compressing to 80 lb. above atmospheric pressure.

One 10 by 6 by 10-in., Worthington, steam, plunger pump.

Three horizontal boilers of the locomotive type, each of 125 h.p.

(*b*).—*Repair Shops.*—The repair shops, which included blacksmith, machine and carpenter shops, were located on the first floor of a 40 by 70-ft. two-story frame structure, which was in the pit on the north side of 31st Street, 48 ft. east of Ninth Avenue. The second floor was on the street level, and was used as a storehouse for hand-tools and small plant.

The blacksmith shop contained: Four forges with hand blowers, four anvils, and hand-tools.

The machine shop contained: One drill press, one shaper (14-in. stroke), one 18-in. swing lathe, and one 6-in. bed lathe.

The carpenter shop contained: One circular saw, one wood lathe, and hand-tools.

The plant in both machine and carpenter shops was operated by one 7½-h.p. General Electric motor, the current for which was obtained from the Edison Electric Heat, Light, and Power Company.

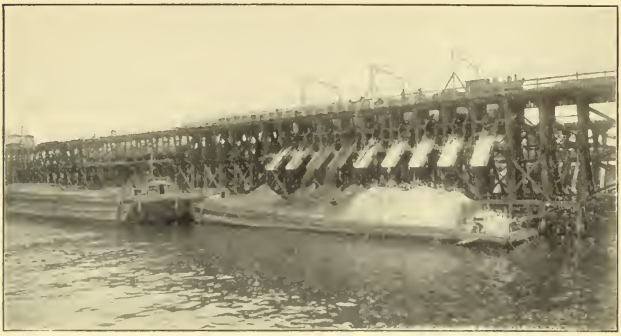


FIG. 1.—MATERIAL TRESTLE, SHOWING FIRST CHUTES IN OPERATION.

FIG. 2.—EAST PIT, STEAM SHOVEL LOADING EXCAVATED MATERIAL ON CAR.

FIG. 3.—WEST PIT, SHOWING CONDITION ON JUNE 28TH, 1905.

2.—Retaining-Wall Plant.

Three cableways, with 35-ft. towers of 12 by 12-in. yellow pine timber capable of spanning 350 ft., and operated by 7 by 10-in. double-drum Lambert hoisting engines mounted with 25-h.p Lambert upright boilers.

Five stiff-leg derricks, with masts from 35 to 50 ft. long and booms from 45 to 60 ft. long, operated by 7 by 10-in. Lambert double-drum and swinging gear engines, mounted with 25-h.p. upright Lambert boilers.

Six Cameron pumps, varying in size from 7 by 6 by 13 in. to 10 by 8 by 16 in. The first dimension referring to the diameter of the steam cylinder, the second to that of the water, and the third to the stroke.

Five Rand sheeting drivers.

Two Ransome ¾-cu. yd. concrete mixers, mounted on frame, with kerosene driving engine.

Drills drawn from pit plant as required.

3.—Pit-Excavating Plant.

One guy derrick, 50-ft. mast and 45-ft. boom, operated by a Lambert two-drum and swing-gear hoisting engine, with Lambert 25-h.p. upright boiler.

Three stiff-leg derricks, similar to those used on the retaining wall work.

Three Bucyrus, 70-ton steam shovels with 3½-cu. yd. dippers.

One traveling derrick, built with an A-frame of 12 by 12-in. timbers, 15-ft. mast, and 25-ft. boom; the traveler carried an engine and boiler similar to those used on the stiff-leg derricks, and was used on the Seventh and Eighth Avenue sewers, as well as in the pit.

Ten Rand-Ingersoll rock drills, Nos. 1, 3¼, and 4.

One Reliance stone crusher (nominal capacity 17 tons of crushed stone per hour) belt-driven by 50-h.p. engine.

4.—Transportation Plant.

During the whole of the first period the transportation plant consisted of two-horse trucks and snatch teams as needed. The number varied greatly from 25 at the beginning and end of

the period to an average of 135 from August 1st to December 1st, 1904, about 10% of the total number of teams being used as snatch teams.

5.—Dock Plant.

The only machinery used on the dock during the horse-and-truck period was one stiff-leg derrick similar in size and operation to those described under the head of retaining-wall plant.

The plant described above does not represent that which was used during the whole of the horse-and-truck period, but what had accumulated at the end of it. The power-generating plant might almost have been omitted from this period, as the first compressor did not begin running until February, 1905. Previous to that time, the power for drilling, pumping, driving, sheeting, etc., was steam furnished by the boilers which subsequently drove the compressors, these being brought on the ground and fired as occasion required.

Train-Disposal Period, Beginning May 22d, 1905.

At the beginning of this period there had been excavated 242 800 cu. yd. of earth and 22 800 cu. yd. of rock, of the total excavation of 803 500 cu. yd. of earth and 804 000 cu. yd. of rock included in the principal contract, leaving to be excavated under that contract 560 000 cu. yd. of earth and 781 200 cu. yd. of rock, and an additional contract had been let to the New York Contracting Company for the terminal power station, which increased the earth by 16 500 and the rock by 15 500 cu. yd. During the year following, contracts for the east and west portions and the sub-structures were let, which brought the total to be excavated, after the beginning of the train-disposal period, up to 681 000 cu. yd. of earth and 1 494 000 cu. yd. of rock.

The central plant, transportation plant, and dock plant were used indiscriminately on all these contracts, and, as no separation can be made which will hold good for any appreciable length of time, the plant in those classes will be stated in total. The retaining-wall and pit plant here given include that used on the principal contract and terminal power station only. The power-generating plant given under the horse-and-truck period was doubled at the beginning of the train-disposal period, but it was still insufficient for the work then under contract, and the additional contracts necessitated a greater increase. The location had also to be changed to permit the excavation of the rock under Ninth Avenue. The old stone church fronting on 34th

Street, between Seventh and Eighth Avenues, a building 68 ft. wide and 92 ft. long, made a roomy and very acceptable compressor-house. The wooden floors and galleries were removed, and good concrete foundations were put in, on which to set the plant; the walls, which were cracked in several places, were trussed apart and prevented from moving outward by cables passed about the pilasters between the windows.

The boilers were erected south of the church, an ash-pit being first built, the full width of it, with the floor on a level with the basement. The rear wall of the church formed the north wall of the ash-pit, and the south wall and the ends were built of concrete. The boilers were set with the fire-doors toward the rear wall of the building, and 7 ft. distant from it, and above this fire-room and the boilers there was erected a coal-bin of 500 tons capacity. The rear wall of the compressor-house formed the north wall of the bin, the section of which was an isosceles right-angled triangle. Coal was delivered by dumping wagons into a large vault constructed under the sidewalk on 34th Street, and was taken from there to the bin by a belt conveyor.

The plant for the second period was as follows:

1.—Central Plant.

(*a*).—*Power-Generating Plant.*—The plant in the engine-room consisted of:

Three Rand straight-line compressors from the original power plant at Ninth Avenue and 32d Street.

One Ingersoll straight-line compressor from the old power-house.

One Rand duplex Corliss, 40 by 48-in. air compressor, with both air and steam cylinders cross-compounded, and a capacity of 5 600 cu. ft. of free air per min. compressed to 80 lb. at 70 rev. per min.

Three Rand duplex, 30 by 30-in., compressors, connected with 525-h.p., 6 600-volt, General Electric motors, with a capacity of 3 000 cu. ft. of free air per min. compressed to 80 lb. at 125 rev. per min.

Two 10 by 6 by 10-in. Worthington steam plunger pumps.

One 7½-h.p. General Electric motor for driving the Robbins belt coal conveyor.

One forced-draft fan (built by the Buffalo Forge and Blower Company), driven by an 8 by 10-in. Buffalo engine.

In the boiler-room there were three 500-h.p. Sterling water-tube boilers.

(*b*).—*Repair Shops.*—The repair shops remained in their old location until sufficient room had been excavated to sub-grade in the lot east of Eighth Avenue, and then they were moved to the old Ninth Avenue power-house which had been erected at that point. The contents of the blacksmith shop remained the same as for the first period. The equipment of the machine shop was increased by one 18-ton trip-hammer operated by air and one bolt-cutting machine, size $\frac{1}{4}$ in. to $1\frac{1}{2}$ in. The carpenter shop remained the same except that the electric motor was replaced by a 25-h.p. single-cylinder air motor; there was added to the repair shop a drill shop containing: Four forges with compressed air blowers, four anvils, two Ajax 20-ft. drill sharpeners, and one oil blower forge.

2.—Retaining-Wall Plant.

The retaining-wall plant was identical with that described for the first period, with the addition of two Ransome 1-cu. yd., concrete mixers, with vertical engines mounted on the same frame, using compressed air.

3.—Pit-Excavating Plant.

The pit-excavating plant included that listed for the first period and, in addition, the following:

One Vulcan, 30-ton, steam shovel, with 1-cu. yd. dipper and a vertical boiler.

One Ohio, 30-ton, steam shovel, with 1-cu. yd. dipper and a vertical boiler.

Four guy derricks (50 to 80-ft. masts and 45 to 60-ft. booms), operated by Lambert 7 by 10-in. engines, with two drums and swinging gear, mounted with 25-h.p. vertical boilers, but driven by compressed air.

Seventy Ingersoll-Rand rock drills, Nos. 1, $3\frac{1}{4}$, and 4.

Two Rand quarry bars, cutting 10 ft. in length at one set-up, and mounted with No. 4 drill using a Z-bit.

4.—Transportation Plant.

Twenty-one H. K. Porter locomotives, 10 by 16-in., and 36-in. gauge.

Three Davenport locomotives, 9 by 16-in., and 36-in. gauge.

One hundred and forty Western dump-cars, each of 4 cu. yd. capacity.

One hundred and sixty-five flat cars, with iron skips, each of 4 cu. yd. capacity.

5.—Dock Plant.

Four stiff-leg derricks on extension, having 35-ft. masts and 40-ft. booms, and each operated by a 60-h.p. Lambert, three-drum, electric, hoisting engine.

One stiff-leg derrick, on the south side of the pier on the upper deck, with a 28-ft. mast operated by a three-drum Lambert engine and a 25-h.p. vertical boiler.

One stiff-leg derrick, on the north side of the dock on the upper deck, used exclusively for bringing in brick, electric conduit, pipe, and other building material, operated when first erected by a three-drum, steam-driven, Lambert, hoisting engine. This engine was later changed to the derrick on the south side of the dock, and a motor-driven Lambert engine from that derrick was substituted.

Eight electric telphers.

Ninth Avenue Twin-Tunnels Plant.

One stiff-leg derrick, previously used in retaining-wall work.

One Smith concrete mixer, 1 cu. yd. capacity, driven by attached air engine.

Two cableways taken from the retaining-wall plant and used for mucking out the tunnels after the center pier had been built; driven by air supplied to the original engine.

One Robbins belt conveyor, driven by a 30-h.p. engine run by air.

Three 1-cu. yd. Hopple dump-cars.

Construction.

Ground was broken for work under the principal contract on July 9th, 1904, on which date the contractor began cutting asphalt for Trench No. 1 in 31st Street, and also began making a roadway from Ninth Avenue into the pit just south of 32d Street.

Excavation for Retaining Walls.—Two essentially different methods were used in excavating for and building the retaining walls; one, construction in trench, the other, construction on bench. In general, the trench method was used wherever the rock on which the wall

was to be founded was 12 ft. or more below the surface of the street; or, what is perhaps a more exact statement, as it includes the determining factor, where the buildings adjoining the wall location were not founded on rock.

In the trench method the base of the wall was staked out on the surface of the ground, the required width being determined by the elevation of the rock, as shown by the borings. The contractor then added as much width as he desired for sheeting and working space, and excavated to a depth of about 5 ft. before setting any timber. In some cases the depth of 5 ft. was excavated before the cableway or derrick for the excavation was erected, the wagons being driven directly into the excavation and loaded by hand, but, usually, the cableway was first erected, and buckets were used from the start. After the first 5 ft. had been excavated, two sets of rangers and struts were set, the first in the bottom of the excavation and the second at the level of the street surface, supported by posts resting on the bottom rangers. The sheeting was then set, and all voids back of it were filled with clean earth and well tamped. The toe of the sheeting was kept level with the bottom of the excavation until the ground-water was reached, after which it was kept from 3 to 5 ft. ahead of the digging.

The sheeting used was 3-in., in variable widths; it was always tongued and grooved on the side of the trench next to the buildings and in the deeper excavations on both sides of the trench, and was driven by wooden mauls above the ground-water level, but steam sheeting-drivers were used below that elevation. Struts, rangers, and posts were generally 12 by 12-in.

Some exceedingly bad material was encountered in the deeper excavations, beds of quicksand being passed through, varying in thickness from 1 to 18 ft., the latter, in 31st Street between Seventh and Eighth Avenues, in the deepest excavation made. After encountering the fine sand in that trench, no headway was made until a tight wooden cylinder was sunk through the sand by excavating the material inside of it and heavily weighting the shell with pig iron. When this cylinder had reached the gravel, which lay below the sand, it was used as a sump, and the water level was kept below the bottom of the excavation, which permitted good progress. Sand continued to flow under the sheeting to such an extent, however, that the front walls of

four adjoining buildings were badly cracked and had to be taken down and rebuilt. All the stoops along this trench settled, and had to be repaired.

The bench method of excavating for the retaining wall was very simple, and was used only where the rock lay near the surface and the adjoining buildings were founded on it, the overlying material being in such case dry, and consequently firm, little or no shoring was required. The method was to extend the pit excavation to a width of 2 or 3 ft. beyond the proposed back of the retaining wall, and to carry that width down to the depth required for its base, below which the excavation was narrowed to 1 ft. inside of the face of the wall and continued either before it was built or subsequently.

Retaining-Wall Construction.—The concrete walls were built in sections 50 ft. in length, except where that spacing would bring an expansion joint under a girder pocket or just on line with a tier of struts, in which cases the section was shortened as required. Trenches were never allowed to remain open at the full depth, the concreting being started as soon after the necessary length of rock had been uncovered as the forms and preliminary work for a section could be prepared. Each section was a monolith, except in a few cases where very heavy rains made it impossible to hold the laborers.

The various operations in building the concrete wall are shown on Fig 7. Guide-planks, *"a a,"* Section *"A-A,"* were securely spiked to alternate tiers of struts for the length of the section, the face of each guide-plank being set on line with the intended face of the concrete wall, and 2-in. tongued-and-grooved spruce plank were laid along the guide-plank to the height of the bottom strut and securely braced from the front sheeting. A 4-in. brick wall was built simultaneously on line with the back of the wall to the height of the first step. Where the bottom strut was below that elevation, the brickwork was left low at that immediate point and built up when the strut was removed. The brick wall was then water-proofed on the side toward the concrete, and loose laps of the water-proofing were allowed to hang over the brickwork and at least 8 in. down the back. A 6-in. vitrified pipe drain was then laid along the surface of the rock just outside of the brick wall, the joints in the pipe being caulked with oakum saturated in cement, and pointed with cement mortar above a line 1 in. below the horizontal diameter, the remainder of each joint being left open. Cross-drains

were laid from tees in the back drain to the face of the wall at all low points in the rock and at least for every 25 ft. of wall length, the joints of these discharge pipes being caulked and cemented throughout. The surface of the rock was then washed and scraped clean, and was covered with about 1 in. of mortar, after which the section was ready for concrete.

The building of monolithic sections in trenches required that the thrust from one set of struts be taken by the concrete before the set above could be removed, and necessarily caused slow progress, the rate at which concrete was deposited being just sufficient to prevent one layer from setting before the next layer above could be placed.

The concrete used was mixed in the proportions of 1 part of cement to 3 parts of sand and 6 parts of stone, in 2-bag batches, in $\frac{3}{4}$-yd. and 1-yd. Ransome portable mixers mounted with air-driven engines on the same frame. These mixers were placed at the surface, and were charged with barrows, the correct quantities of sand and stone for each batch being measured in rectangular boxes previous to loading the barrows. The concrete was discharged from the mixer into a hopper which divided into two chutes, only one of which was used at a time, the concrete being shoveled from the bottom of the chutes to its final position. Facing mortar, 2 in. thick, was deposited simultaneously with the concrete, and was kept separate from it by a steel diaphragm until both were in place, when the diaphragm was removed and the two were spaded together. The bottoms of the guide-planks were cut off just above the concrete as it progressed, and, as soon as the wall had reached a strut at one end of the section, that strut was removed, the form was built up to the next strut, at front and back, and braced to the sheeting, so that, by the time the entire length of the section had been carried up to the level of the first line of struts, forms were ready at one end for the succeeding layers. The layers of concrete never exceeded 8 in. in height, and at times there were slight delays in the concreting while the carpenters made ready the next lift of forms, but such delays were rarely long enough to permit the concrete to take its initial set.

After a section of concrete had firmly set, both back and front forms were removed, and the thrust from the sides of the trench was transferred directly to the finished wall. The face of the wall was rubbed with a cement brick to remove the marks of the plank, and

SKETCH SHOWING FORMS FOR, AND METHOD OF,
CONCRETING RETAINING WALLS IN TRENCH.

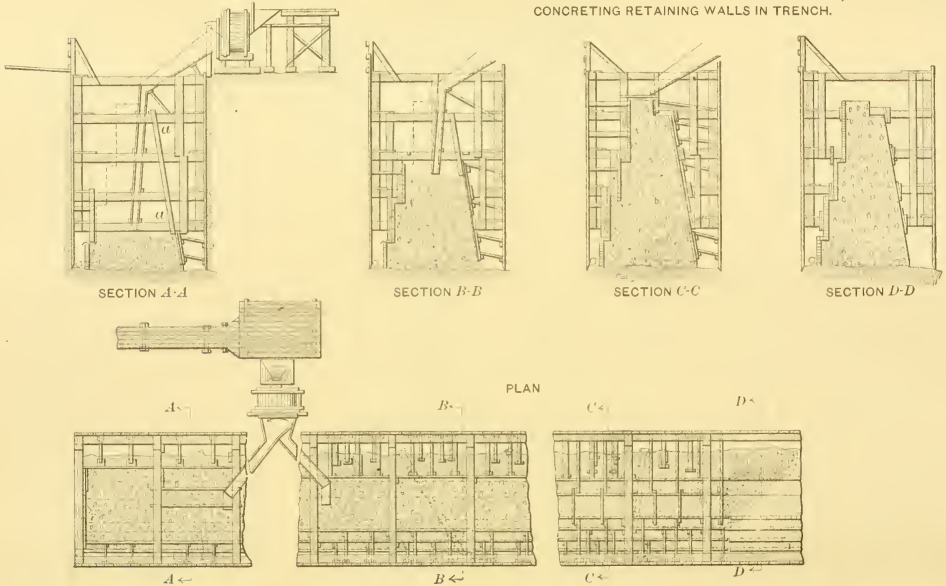


FIG. 7.

was then coated with a wash of thin cement grout. The water-proofing and brick armor were then continued up the back of the wall, the spaces between the lines of braces being first water-proofed and bricked, and the braces transferred to the finished surface, after which the omitted panels were completed. The water-proofing consisted of three layers of Hydrex felt, of a brand known as Pennsylvania Special, and four layers of coal-tar pitch. The pitch contained not less than 25% of carbon, softened at 60° Fahr., and melted at a point between 96° and 106° Fahr. The melting point was determined by placing 1 gramme of pitch on a lead disk over a hole, $\frac{5}{16}$ in. in diameter, and immersed in water which was heated at the rate of 1° per min.; the temperature of the water at the time the pitch ran through the hole was considered as the melting point.

In order to prevent the water-proofing from being torn at the joint between sections when they contract from changes in temperature, a vertical strip of felt, 6 in. wide, was pitched over each joint, lapping 3 in. on each concrete section. The back of this strip was not pitched, but was covered with pulverized soapstone, so that the water-proofing sheet was free from the wall for a distance of 3 in. on either side of each joint.

Concreting was continued during the severest weather, one section being placed when the thermometer was 5° above zero. When the thermometer was below the freezing point both sand and stone were heated by wood fires in large pipes under the supply piles; the temperature of the mix was taken frequently, and was kept above 40 degrees. Numerous tests made while the work was in progress showed that, while the temperature fell slightly soon after the concrete was deposited, it was always from 2° to 5° higher at the end of 2 hours. The face and back of the concrete were prevented from freezing by a liberal packing of salt hay just outside the forms.

A vertical hog trough, 24 in. wide and 9 in. deep, was placed in one end of each section, for its full height below the bridge seat, into which the next section keyed, and, when the temperature at the time of concreting was below 50° Fahr., a compression joint was formed by placing a strip of heavy deadening felt, 2 ft. wide, on the end of the completed section next to the face and covering the remainder of the end with two ply of the felt and pitch water-proofing; the one ply of deadening felt near the face was about the same thickness as the

two ply of water-proofing, and was used to prevent the pitch from being squeezed out of the joint to the face of the wall.

The excavation for the retaining walls in 31st and 33d Streets were in all cases made of sufficient width to receive the sewers, which were laid as soon as the back-fill, carefully rammed and puddled, had reached the proper elevations; the back-filling was then completed, and the gas and water mains were afterward laid in separate trenches.

The sections of concrete built in trench varied in height from 13 to 59 ft. from the base to the top of the back wall. With the exception of the Seventh Avenue wall, 50 ft. in height, and the Ninth Ave-

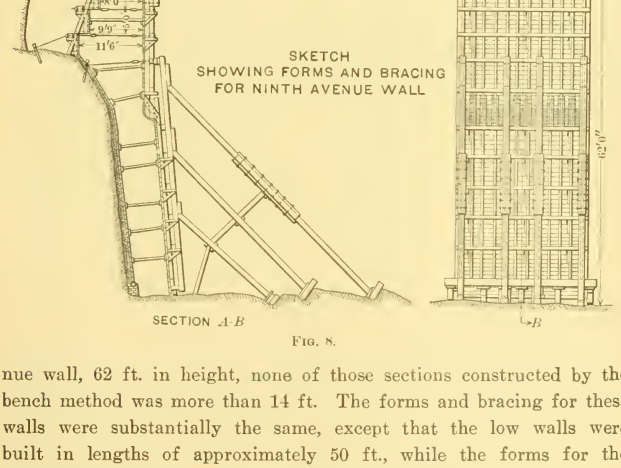


FIG. 8.

nue wall, 62 ft. in height, none of those sections constructed by the bench method was more than 14 ft. The forms and bracing for these walls were substantially the same, except that the low walls were built in lengths of approximately 50 ft., while the forms for the Seventh and Ninth Avenue walls were only 20 ft. long.

The forms and bracing for the Ninth Avenue walls are shown on Fig. 8. These forms were built in one piece and moved ahead from section to section, and they were firmly braced from the bottom with raker braces to a point 36 ft. above the base, the upper part being held in place by $\frac{3}{4}$-in. bolts passed through the forms and anchored by cables to bolts grouted into the rock behind.

After the forms had been set and braced, an 8-in. brick wall was laid up the face of the rock, containing a vertical line of three-cell hollow tile block every 5 ft. of length, and laid to conform as nearly as possible to the face of the rock, all voids being filled with broken stone. Water-proofing, similar to that described for the walls in the trench, was then applied to the brick and tile wall for the full height, and firmly braced to the front forms, the braces being removed as the concrete reached them. The concrete was mixed at the street level and deposited through chutes, as described previously.

Tables 1, 2, and 3 show the quantity of cement used in each section of retaining wall, and give figures by which the quantities of other materials may be determined.

Pit Excavation.—The pit excavation during the horse-and-truck period was largely preparatory work done to get the excavation in good shape for handling spoil trains after Pier No. 72 and the trestle approach were finished. This required an open cut from Ninth to Seventh Avenues at a sufficient depth below the sewers and other substructures in the avenues to clear a locomotive, and wide enough for both running and loading tracks, also the building of the cast-iron sewer in Eighth Avenue across the entire excavation, with enough of the temporary bridging to support it. The building of the trestle in Eighth Avenue was essentially a part of the pit excavation, as the progress of one depended greatly on that of the other.

Excavation was commenced on July 12th, 1904, for the crossing under Ninth Avenue, and in the pit east of Ninth Avenue along 32d Street. The line chosen for the opening cut was down the center of the pit, as it was not safe to excavate near the bounding streets until after the completion of the enclosing retaining wall. The excavation was started by hand, but three 70-ton Bucyrus steam shovels were put to work as soon as they could be delivered, the first on July 25th and the third on September 12th. The excavated material was loaded by the shovels on end-dump wagons, each having a capacity of 2 cu. yd., and was conveyed in them to the dumping board at 35th Street. The average number of teams was 135, 10% being snatch teams to pull the wagons out of the pit and to assist them up the runway at the dumping board. The teams averaged only seven trips per day of 10 hours, considerable delay being caused by the trains of the New York Central Railroad at Eleventh Avenue. The number of teams

was not sufficient, therefore, to keep the three shovels busy when they were all in good digging, but the dumping board was taxed to accommodate that number, and little would have been gained by increasing it. The digging was very good during this period, practically no rock being encountered, and the building foundations were too light to present any obstacle to such powerful shovels. The capacity of their dippers was 3½ cu. yd., so that one dipperful meant one truck loaded and running over. The output from August to November, inclusive, averaged 40 000 cu. yd. per month; one shift only was worked per day, and although the quantity was not large for three such powerful shovels, it was large to truck through the streets, and required that

SKETCH SHOWING TYPICAL BENT OF TRESTLE SUPPORTING EIGHTH AVENUE

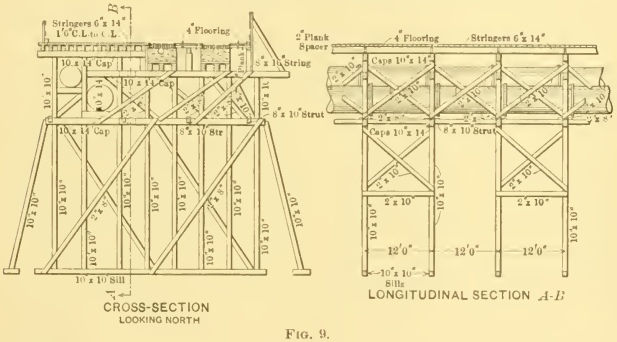


FIG. 9.

one team pass a given point every 18 sec. At the end of November the opening up of the pit had been accomplished, considerable rock had been stripped near Ninth Avenue, and the streets had become so icy that the cost of transportation was practically doubled; work in the pit, therefore, was much curtailed, and amounted to continuous work for one shovel from that time until the end of the period, May 22d, 1905, when Pier No. 72 was put in service and transportation by train began. Figs. 2 and 3, Plate LVI, show the condition of the pit east and west of Eighth Avenue, respectively, on that date.

The work of excavating for and building the temporary street bridge, a typical bent and bracing for which are shown on Fig. 9, and the cast-iron sewer and water mains in Eighth Avenue, was com-

menced on September 3d, 1904. The trestle was a double-decked structure of yellow pine, with 10 by 10-in. posts and sills, 10 by 14-in. intermediate and top caps, and 2 by 10-in. longitudinal and cross-braces. The trestle was further stiffened longitudinally by four lines of 8 by 10-in. struts, butted between the intermediate caps, and held in position by 2 by 8-in. splice-plates resting on top of them. The intermediate caps were at an elevation of 15 ft. below the surface of the street, and above that line the longitudinal bracing was continuous, while below it the bents were braced in pairs, the bracing being omitted from every second bay. Below the intermediate cap the bents were uniform for the entire width of the trestle, but the top cap was not continuous, being 5 ft. below the surface under the trolley tracks, and only 18 in., the depth of stringers and planking, beyond. The stringers under the trolley tracks were 8 by 16-in. yellow pine, spaced three to a track, and those for the driveway were 6 by 14-in., spaced 1 ft. 6 in. on centers, the planking being 4-in. yellow pine.

The first step in the construction was to excavate a trench 15 ft. wide on the west side of the street, the east side of the trench being 4 ft. west of the westernmost trolley rail. While this work was in progress, all vehicular traffic was turned to that part of the avenue east of the westerly trolley rail. The trench was sheeted and timbered, and carried to a depth sufficient to receive the intermediate cap. That portion of the bent from the bottom of the intermediate cap to the bottom of the top cap was then erected for the width of the trench, after which the 60-in. cast-iron sewer and the 48-in. water main were laid in position and caulked. The top cap, stringers, and planking were then laid, for the full width of the trestle west of the trolley tracks. This work was finished and the sewage turned into the new sewer in April, 1905.

As the planking was laid west of the trolley tracks, traffic was turned to that side of the street, and the material east of the tracks was excavated to its natural slope. Trenches were then dug under the tracks on the line of the bents, and the caps were set in position on blocking. The material between these trenches was then removed, the tracks being supported meanwhile by blocking at least every 6 ft., and the stringers and planking were shoved into place. Excavation was next made between the caps to a depth of about 5 ft. below them, needle-beams being placed under the caps, one or two at a time, and

supported on posts erected in these excavations; the material on line of the bents was excavated to the depth of the intermediate caps, which were then set, together with the posts and bracing for the upper deck of the structure. This operation was repeated for the lower deck, about 10 ft. being gained for each change of posts, and three shifts, therefore, were required.

At the beginning of the train-transportation period, May 22d, 1905, two shifts of 10 hours each were inaugurated, and the earth was handled at the rate of from 85 000 to 90 000 cu. yd. per month; but, by the end of August, when a little more than 60% of the total earth had been disposed of, the rock began to interfere very greatly with the progress. The strike of the rock was almost directly north and south, and its surface formed broken ridges running in that direction, with deep valleys between. The dip was almost vertical near Ninth Avenue, and about 70° toward the west near Seventh Avenue. This condition made it necessary to turn the shovels parallel to the ridges in order to strip the rock for drilling; and, as the ridges were very broken, the shovels continued to bump into them on all occasions, making it necessary to move back and start other cuts or stand and wait for the rock to be drilled and blasted. One small Vulcan steam shovel, with vertical boiler and ¾-cu. yd. dipper, had been brought on the work to be used in stripping rock, and was moved from place to place so much more easily than the large ones that an Ohio shovel of the same general type was purchased in October, and thereafter the stripping was done largely by the two small shovels and by hand, the large shovels being used almost exclusively in handling rock.

The drilling necessary to remove the rock was very large in amount and also per yard excavated. In order not to damage the retaining walls and the rock underlying them, holes spaced at 5-in. centers were drilled 1 ft. away from the face of the walls and on the same batter. These breaking holes alone amounted to a total of 210 000 lin. ft., or 1 ft. of hole for each 3½ cu. yd. of rock excavated; and the regulations of the Bureau of Combustibles, which prevented springing, caused the blasting holes to be placed very close together and required a total of about 420 000 lin. ft., making 630 000 ft. If to this is added the block holes, for some of the rock broke very large, it will show at least 1 ft. of drill hole for each cubic yard of rock excavated, about ten times the average on general railroad work.

TABLE 1—(*Continued*).

21.....	172 + 12.0 172 + 45.2	271.48	31.75	10.80	2.50	0.85	8.65	251.18	311.50	1.24	5/29/05	6/3/05
22.....	168 + 41.3 168 + 72.6	316.30	44.00	14.97	5.25	1.79	7.18	292.36	338.75	1.16	6/5/05	6/10/05
23.....	173 + 63.6 174 + 04.5	529.33	54.75	18.63	4.75	1.62	1.25	507.83	587.25	1.16	6/5/05	6/13/05
24.....	167 + 92.6 168 + 41.3	1 010.64	66.00	22.46	5.50	1.87	10.16	976.15	1 038.75	1.07	6/8/05	6/21/05
25.....	173 + 21.2 173 + 63.6	675.21	77.75	26.46	2.50	0.85	12.00	635.90	776.25	1.22	6/16/05	6/24/05
26.....	164 + 72.5 165 + 05.8	458.22	40.00	13.61	5.50	1.87	22.37	420.37	532.00	1.26	6/23/05	6/28/05
27.....	172 + 81.9 173 + 21.2	409.43	35.00	11.91	9.75	3.31	4.64	389.57	450.00	1.16	6/27/05	7/7/05
28.....	164 + 27.6 164 + 72.5	658.46	72.00	24.50	1.50	0.51	16.40	617.05	726.25	1.18	6/29/05	7/7/05
29.....	172 + 45.2 172 + 81.9	345.89	30.25	10.29	5.00	1.70	1.62	332.28	384.00	1.16	7/11/05	7/19/05
31.....	174 + 78.0 175 + 18.5	507.50	35.75	12.17	3.00	1.02	17.09	477.22	567.50	1.19	7/29/05	8/6/05
32.....	174 + 29.6 174 + 78.0	396.99	43.75	14.89	1.75	0.60	6.50	375.00	434.25	1.16	8/5/05	8/12/05
43.....	177 + 94.9 178 + 44.1	194.07	30.00	10.21	2.00	0.68	8.35	174.83	219.75	1.26	11/9/05	11/12/05
Pier	168 + 72.6 168 + 81.1	106.52	.....	.....	.....	.....	.....	106.52	144.00	1.35	12/6/06	12/8/06
76.....	178 + 44.1 178 + 94.1	136.32	12.75	4.34	4.75	1.62	.....	130.36	142.50	1.09	7/8/07	7/10/07
79.....	178 + 94.1 179 + 44.1	118.07	9.00	3.06	3.50	1.19	.....	113.82	129.50	1.14	7/15/07	7/16/07
82.....	179 + 44.1 179 + 93.7	126.12	6.50	2.21	2.50	0.85	.....	123.06	131.75	1.07	7/22/07	7/23/07
84.....	179 + 93.7 180 + 44.2	126.77	6.75	2.30	2.25	0.77	.....	123.70	133.50	1.08	7/26/07	7/27/07
86	180 + 44.2 180 + 93.6	162.48	8.00	2.72	2.75	0.94	.....	158.82	167.00	1.05	7/30/07	7/31/07
90.....	180 + 93.6 181 + 17.9	92.52	4.00	1.36	1.00	0.34	.....	90.82	115.00	1.27	8/18/08	8/18/08

NOTE.—The number of cubic yards of crushed stone used in any section can be found by multiplying the figure for that section in Column 10 by 0.7778.

The number of cubic yards of sand used in any section can be found by multiplying the sum of the figures for that section in Columns 4, 6, and 10 by 0.3889.

REMARKS.—Section No. 4. Amount of sand cut down on a part of this section on account of dust in stone.
Section No. 8. O'Rourke stone used on this section, large and full of dust.
Section No. 9. Stone crushed on the work used on this section, large and full of dust.
Section No. 21. 1 : 3 : 5 mix was used in part of this section on account of stone being large.
Section No. 24. Different sized stone was shipped on barge and mixed on the board for this section.
Section No. 25. 1 : 3 : 5 mix used in a small part of this section on account of stone being large.
Sections Nos. 76, 82, 84, and 86. Stone contained large amount of dust.

TABLE 1.—Record of Retaining-Wall Sections, Terminal Station.

West Thirty-first Street from Seventh Avenue to Ninth Avenue.

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
1.....	165 + 05.8 165 + 66.0	617.48	17.50	5.95	.....	.....	.....	611.53	731.50	1.20	11/4/04	11/20/04
2.....	165 + 66.0 165 + 95.4	233.96	10.25	3.49	.....	.....	.....	230.47	277.25	1.20	11/21/04	11/27/04
3.....	165 + 95.4 166 + 41.2	355.20	24.50	8.34	.....	.....	.....	346.86	398.25	1.15	11/26/04	12/3/04
4.....	171 + 03.4 171 + 53.4	309.29	67.50	23.00	.....	.....	.....	286.29	360.50	1.26	12/2/04	12/10/04
5.....	177 + 44.0 177 + 94.0	109.62	30.25	10.30	.....	.....	.....	99.32	120.75	1.22	12/28/04	12/30/04
6.....	171 + 53.4 171 + 83.0	246.35	27.75	9.44	.....	.....	.....	236.91	292.50	1.23	1/2/05	1/11/05
7.....	166 + 41.2 166 + 79.0	644.12	77.50	26.37	.....	.....	.....	617.75	737.00	1.19	1/13/05	2/4/05
8.....	171 + 83.0 172 + 12.0	394.43	68.75	21.69	.....	.....	.....	372.74	420.75	1.13	1/14/05	1/28/05
9.....	166 + 79.0 167 + 20.5	974.58	103.75	35.30	2.50	0.85	7.96	930.47	1 066.25	1.14	2/18/05	3/13/05
10.....	170 + 16.6 170 + 58.6	767.34	92.50	31.48	2.75	0.94	.....	734.92	852.50	1.16	1/31/05	2/25/05
11.....	170 + 58.6 171 + 03.4	599.17	77.00	26.20	10.25	3.49	.....	569.48	689.75	1.21	3/11/05	3/23/05
12.....	167 + 20.5 167 + 43.9	585.28	50.50	17.18	2.00	0.68	4.00	513.42	611.75	1.19	3/9/05	3/26/05
13.....	175 + 18.5 175 + 61.8	553.04	62.00	21.10	5.25	1.79	.....	530.15	630.50	1.19	3/15/05	3/29/05
14.....	177 + 02.9 177 + 44.0	305.12	49.25	16.76	4.50	1.53	.....	286.83	340.25	1.19	3/26/05	3/31/05
15.....	175 + 61.8 175 + 91.7	429.88	50.00	17.01	1.50	0.51	.....	412.36	472.50	1.15	3/28/05	4/14/05
16.....	176 + 62.5 177 + 02.9	675.64	77.50	26.37	6.25	2.13	.....	647.14	788.00	1.22	4/1/05	4/17/05
17.....	174 + 04.5 174 + 29.6	162.98	29.00	9.87	3.50	1.19	.....	151.92	182.50	1.20	5/3/05	5/6/05
18.....	175 + 91.7 176 + 21.5	698.88	46.25	15.72	4.50	1.53	15.86	665.77	801.00	1.20	5/9/05	5/19/05
19.....	176 + 21.5 176 + 62.5	1 166.79	81.50	27.73	4.00	1.36	34.96	1 102.74	1 354.50	1.23	5/15/05	5/28/05
20.....	167 + 43.9 167 + 92.6	975.53	95.75	32.58	3.25	1.11	36.99	904.85	1 012.75	1.12	5/25/05	6/3/05

TABLE 2—(*Continued*).

49.....	177 + 81.1 178 + 24.1	241.51	25.25	8.59	2.50	0.85	1.33	230.74	274.00	1.19	5/21/06	5/24/06
50.....	168 + 03.6 168 + 45.6	405.61	25.50	8.68	4.00	1.36	36.10	359.47	406.00	1.13	6/13/06	6/18/06
51.....	177 + 38.4 177 + 81.1	100.54	12.75	4.34	3.00	1.02	0.78	94.40	112.00	1.19	6/20/06	6/21/06
52.....	168 + 45.6 168 + 80.1	181.96	19.00	6.47	1.00	0.34	9.03	166.12	190.00	1.14	6/25/06	6/28/06
53.....	168 + 80.1 169 + 00.1	41.32	3.50	1.19	.....	.....	.....	40.13	44.50	1.11	6/29/06	6/29/06
55.....	176 + 90.0 177 + 38.4	92.41	11.25	3.83	2.50	0.85	3.68	84.05	98.25	1.17	8/17/06	8/18/06
56.....	167 + 62.1 168 + 03.6	388.67	33.75	11.48	3.25	1.11	36.62	334.46	383.50	1.14	8/28/06	9/1/06
59.....	175 + 67.3 175 + 98.9	175.61	15.50	5.27	2.50	0.85	9.37	160.12	186.00	1.16	10/15/06	10/16/06
60.....	176 + 49.0 176 + 90.0	69.97	8.25	2.81	3.00	1.02	1.58	64.56	75.00	1.16	10/17/06	10/18/06
61.....	175 + 98.9 176 + 49.0	104.56	8.00	2.72	3.50	1.19	3.72	96.93	108.00	1.11	10/19/06	10/20/06
64	175 + 30.3 175 + 67.3	140.15	14.75	5.02	2.75	0.94	.....	134.19	161.50	1.20	11/21/06	11/22/06
65.....	174 + 85.4 175 + 30.3	80.66	9.00	3.06	2.50	0.85	.....	76.75	92.75	1.21	12/14/06	12/15/06
66	174 + 47.9 174 + 85.4	68.89	5.50	1.87	3.25	1.11	.....	65.91	83.50	1.27	12/18/06	12/18/06
67.....	174 + 21.1 174 + 47.9	60.14	3.00	1.02	2.00	0.68	0.92	57.52	67.50	1.17	12/21/06	12/21/06
68.....	167 + 12.3 167 + 62.1	379.94	23.50	8.00	5.00	1.70	19.34	350.90	412.50	1.17	1/2/07	1/6/07
69.....	173 + 85.6 174 + 21.1	77.43	6.50	2.21	3.00	1.02	.....	74.20	91.00	1.23	1/29/07	1/30/07
70.....	166 + 75.6 167 + 12.3	408.81	33.75	11.48	3.75	1.28	.....	396.05	468.50	1.18	4/2/07	4/10/07
71.....	173 + 46.5 173 + 85.6	85.92	8.25	2.81	1.75	0.60	.....	82.51	95.75	1.16	4/17/07	4/19/07
74.....	172 + 19.2 172 + 73.0	449.28	22.75	7.74	6.25	2.13	.....	439.41	506.00	1.15	6/20/07	6/24/07
75.....	172 + 73.0 173 + 24.0	502.20	27.25	9.27	7.00	2.38	.....	490.55	579.00	1.18	7/8/07	8/25/07
77.....	164 + 77.0 165 + 27.1	141.38	9.00	3.06	7.25	2.47	.....	135.85	161.50	1.19	7/13/07	7/15/07
78.....	168 + 83.4 169 + 18.3	63.35	3.00	1.02	1.50	0.51	.....	61.82	73.00	1.18	7/13/07	7/14/07

TABLE 2.—Record of Retaining-Wall Sections, Terminal Station.

West Thirty-third Street from Seventh Avenue to Ninth Avenue.

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
30	170 + 73.2 171 + 16.1	364.72	42.50	14.46	4.00	1.36	.....	348.90	391.00	1.12	7/20/05	7/26/05
33	178 + 48.7 178 + 84.1	180.40	29.50	10.04	3.50	1.19	.....	169.17	188.00	1.11	8/7/05	8/11/05
34	R 2 + 75.5 170 + 03.6	214.12	38.00	12.93	1.60	0.34	1.50	199.35	217.25	1.09	8/14/05	8/19/05
35	171 + 16.1 171 + 42.5	381.56	40.25	13.70	1.00	0.34	14.37	353.15	400.25	1.13	8/16/05	8/22/05
36	170 + 03.6 170 + 25.0	150.16	20.50	6.98	.....	.....	6.25	136.93	133.75	0.98	8/19/05	8/22/05
37	171 + 42.5 171 + 91.3	869.40	59.50	20.25	4.50	1.53	44.96	802.66	909.00	1.13	8/22/05	9/6/05
38	171 + 91.3 172 + 19.2	233.49	22.75	7.74	2.75	0.94	14.45	210.36	238.50	1.13	8/24/05	8/27/05
39	179 + 27.2 179 + 64.2	255.39	32.00	10.89	3.00	1.02	9.05	234.43	270.25	1.15	8/29/05	9/2/05
40	170 + 25.0 170 + 73.2	500.73	44.25	15.06	1.00	0.34	29.64	455.69	525.75	1.15	9/11/05	9/15/05
41	169 + 50.8 R 2 + 75.5	215.93	28.25	9.61	2.00	0.68	.....	205.64	236.50	1.15	10/3/05	10/6/05
42	178 + 84.1 179 + 27.2	177.62	23.00	7.83	1.50	0.51	7.06	162.22	194.75	1.20	10/9/05	10/11/05
44	180 + 05.5 180 + 44.2	936.15	58.75	19.99	10.50	3.47	73.84	838.85	987.00	1.18	11/17/05	11/27/05
45	180 + 44.2 180 + 74.9	1 133.69	60.00	20.42	5.00	1.70	60.71	1 050.86	1 206.00	1.15	12/13/05	12/23/05
46	179 + 64.2 180 + 05.5	477.14	35.00	11.91	3.75	1.28	24.58	439.37	535.00	1.22	1/15/06	1/19/06
47	169 + 00.1 169 + 50.8	136.19	14.25	4.85	3.50	1.19	2.00	128.15	150.50	1.17	4/4/06	4/6/06
48	178 + 24.1 178 + 48.7	192.78	21.25	7.23	2.00	0.68	.....	184.87	226.00	1.22	4/24/06	4/30/06

TABLE 2—(*Continued*).

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
80	165 + 27.1 165 + 76.6	108.86	11.75	4.00	3.00	1.02	.....	103.84	133.50	1.28	7/18/07	7/19/07
81	168 + 45.6 168 + 88.4	210.97	13.00	4.42	6.25	2.13	.....	204.42	255.75	1.25	7/20/07	7/23/07
83	165 + 76.6 166 + 20.5	108.06	8.00	2.72	3.75	1.28	.....	104.06	128.50	1.23	7/25/07	7/27/07
85	166 + 20.5 166 + 64.6	107.52	9.00	3.06	2.25	0.76	.....	103.70	144.50	1.39	7/29/07	7/30/07
87	166 + 64.6 166 + 75.6	23.44	1.00	0.34	.25	0.42	.....	22.68	30.00	1.32	7/31/07	7/31/07
88	164 + 26.3 164 + 77.0	317.72	24.00	8.17	2.25	0.76	.....	308.79	370.00	1.20	8/8/07	8/11/07
89	173 + 20.8 173 + 46.5	93.51	5.00	1.70	1.50	0.51	.....	91.30	121.75	1.33	9/7/07	9/8/07
91	180 + 74.9 180 + 92.7	141.40	17.50	5.96	.....	.....	.....	135.44	203.50	1.50	11/18/08	11/20/08
92	180 + 92.7 181 + 28.8	118.93	19.00	6.46	.....	.....	.....	112.47	190.00	1.69	12/1/08	12/2/08

NOTE.—The number of cubic yards of crushed stone used in any section can be found by multiplying the figure for that section in Column 10 by 0.7778.

The number of cubic yards of sand used in any section can be found by multiplying the sum of the figures for that section in Columns 4, 6, and 10 by 0.3889.

REMARKS.—Section No. 47. Part of this section was removed on account of damage done by blasting and was replaced by Section No. 78.
Section No. 52. All of this section was removed on account of damage done by blasting and was replaced by Section No. 81.
Section No. 53. All of this section was removed on account of damage done by blasting, and was replaced by Sections Nos. 78 and 81.

TABLE 3.—Record of Retaining Wall Sections.

Power-House.

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
A	L 2 + 75.3 L 3 + 25.3	463.28	58.25	19.82	5.50	1.87	11.50	430.09	482.75	1.12	5/18/05	5/25/05
B	L 3 + 25.3 L 3 + 74.9	114.78	23.00	7.83	1.75	0.60	1.50	104.85	125.50	1.20	6/14/05	6/16/05
C	169 + 30.8 169 + 74.8	179.19	34.25	11.66	1.00	0.34	3.60	163.59	183.00	1.12	7/10/05	7/13/05
D	169 + 74.8 170 + 28.8	114.38	27.25	9.27	0.25	0.09	0.07	104.95	119.25	1.14	7/14/05	7/19/05
E	168 + 83.6 169 + 30.8	101.20	22.00	7.49	1.50	0.51	0.65	92.55	107.25	1.16	7/26/05	7/28/05
F	L 2 + 78.2 L 3 + 19.6	358.80	39.50	13.44	0.75	0.26	9.50	335.60	397.75	1.18	9/19/05	9/24/05
G	L 3 + 19.6 L 3 + 56.9	237.33	23.00	7.83	1.00	0.34	0.74	228.42	278.00	1.22	9/26/05	9/29/05
H	L 3 + 56.9 168 + 83.6	25.55	6.25	2.13	0.75	0.26	.....	23.16	28.00	1.21	9/29/05	9/29/05

Seventh Avenue.

54	164 + 27.6 L 2 + 32.0	764.48	69.75	23.74	3.00	1.02	.....	739.72	907.50	1.23	8/6/06	8/15/06
57	L 2 + 10.3 L 2 + 32.0	533.06	34.00	11.57	2.25	0.77	.....	520.72	610.75	1.17	9/10/06	9/15/06
58	L 1 + 87.1 L 2 + 10.3	544.54	32.25	10.97	2.00	0.68	9.80	523.09	588.25	1.12	9/24/06	9/28/06
62	L 1 + 87.1 L 1 + 64.4	575.67	30.00	10.21	3.00	1.02	26.20	558.24	639.50	1.19	10/21/06	10/29/06
63	L 1 + 64.4 L 1 + 42.4	607.01	30.50	10.38	2.50	0.85	13.79	581.99	678.50	1.17	11/5/06	11/11/06
72	L 1 + 42.4 L 1 + 19.6	681.97	30.00	10.21	1.75	0.60	1.18	619.98	719.50	1.16	4/25/07	4/30/07
73	L 1 + 19.6 L 0 + 97.0	573.33	25.25	8.59	0.25	0.08	2.48	562.18	685.75	1.22	5/13/07	5/18/07

Note.—The number of cubic yards of crushed stone used in any section can be found by multiplying the figure for that section in Column 10 by 0.7778. The number of cubic yards of sand used in any section can be found by multiplying the sum of the figures for that section in Columns 4, 6, and 10 by 0.3889.

Channeling with a 10-ft. quarry bar, carrying a No. 4 Ingersoll-Rand drill with Z-bits, was attempted in place of the close drilling below the walls, but, as the rock stood so nearly vertical and was full of soft seams, very little could be accomplished, the average cut per day of 10 hours, counting the time of moving and setting up, was only 4 sq. ft., and, after a thorough trial, the bars were abandoned.

Disposal.—The excavated material was hauled from the shovels to the pier in 10-car trains. The cars were of three classes: 4-yd. Western dump-cars, flat cars without skips, and flats carrying specially designed steel skips having a capacity of 4 cu. yd. each. As far as practicable, earth, and rock containing 1 cu. yd. or less, was loaded on dumpers, medium-sized rock on the skips, and large rock on the bare flats. As a steam shovel must pick up what is nearest to it first, however, this classification could not always be adhered to, and many large rocks were loaded into dumpers. Cars of this class which contained no material too large to dump were run at once to the hoppers, and were dumped and returned to the pit; others, together with the flat and skip cars, were run down the incline to the derricks and telphers, where the flats and skips were entirely unloaded, and the large rocks were removed from the dumpers, after which they were run to the hoppers and emptied.

The total quantity of excavated material handled at this pier from May 22d, 1905, to December 31st, 1908, amounted to 673 800 cu. yd. of earth and 1 488 000 cu. yd. of rock, place measurement, equal to 3 203 400 cu. yd., scow measurement; in addition to which 175 000 cu. yd. of crushed stone and sand and 6 000 car loads of miscellaneous building material were transferred from scows and lighters to small cars for delivery to the Terminal work.

All the earth and 570 000 cu. yd. of the rock, place measurement, were handled through the chutes, and the remainder of the rock, 918 000 cu. yd., and all the incoming material by the derricks and telphers. In capacity to handle material, one telpher was about equal to one derrick. A train, therefore, could be emptied or a boat loaded under the bank of eight telphers in one-fourth the time required by the derricks, of which only two could work on one boat. The telphers, therefore, were of great advantage where track room and scow berths were limited.

As noted in the list of contracts under which the work was exe-

cuted, the scows at both the 35th Street dumping board and Pier No. 72 were furnished, towed, and the material finally disposed of, by Henry Steers, Incorporated. During the same period, this contractor disposed of the material excavated from both the Cross-town Tunnels, constructed by the United Engineering and Contracting Company, and the tunnels under the East River, constructed by S. Pearson and Son, Incorporated. As stated in other papers of this series relating to the construction of those tunnels, the material excavated by the United Engineering and Contracting Company was delivered to barges at 35th Street and East River and that by S. Pearson and Son, Incorporated, at two points, one in Long Island City and the other at 33d Street and East River, Manhattan.

The total number of cubic yards of material disposed of amounted to:

	Place measurement. Earth.	Rock.	Total barge measurement.
35th Street and North River	242 800	22 800	281 500
Pier No. 72, North River	673 800	1 488 000	3 203 400
From Cross-town Tunnels			570 400
From Under-river Tunnels			402 500
Total			4 457 800

The material was delivered as follows:

To the freight terminal of the Pennsylvania Railroad Company at Greenville, N. J.	3 454 800
To the Meadows Division of the Tunnel Line between Harrison, N. J., and the North River Portals	711 900
To other points selected by the contractors	291 100
Total	4 457 800

The handling of this large quantity of material required the loading of from 10 to 20 scows per day (and for more than two years the average was 14), and, as the average time spent in one round trip was 3¾ days, a fleet of more than 50 scows was required to keep all points supplied and allow for a few to be out of service undergoing repairs.

All loaded scows were towed from the docks, with the ebb tide, to a stake boat anchored in the bay about one mile off shore at Greenville; and were taken from there to the different unloading points, as required, by smaller tugs which also returned the empty scows to the stake.

The unloading plants were similar at the different points, although that at Greenville was much larger than the others. It included five land dredges and eight traveling derricks of two types, one floating and the other mounted on wheels and traveling on a track of 16-ft. gauge. The derricks handled the large rock, which was loaded at Pier No. 72 by derricks and telphers. They were of the ordinary A-frame type, and were designed to handle 20 tons. They were operated by 9 by 10-in. Lidgerwood double-drum and swinging-gear engines. The large rock was deposited by the derricks either in the channels along which they worked or in the fill along shore, without the use of cars. The land dredges were equipped with a 60-ft. boom and a 2½-yd. Hayward bucket operated by a 14 by 18-in. double-drum Lidgerwood dredging engine. They loaded into 9-yd., standard-gauge, side-dump cars, built by the contractor, and unloaded the scows to within about 1 ft. of the deck, a Hayward bucket being unsuitable for closer work without greatly damaging the scows. The material remaining was loaded by hand into skips which were handled to the cars by small derricks, one of which was located at the rear of each dredge. The cars were taken to the dump and returned by 25-ton, standard-gauge, engines which had previously done service on the Manhattan Elevated Railroad, but were spotted for loading by the engine on the dredge.

In order to keep a record of the fleet of scows, which would show the available supply at a glance, a board, 10 by 15 in., and covered with a heavy sheet of ruled paper, was arranged as shown by Fig. 10. It was divided into 12 vertical columns, the first of which was headed "Scows," and contained the name or number of each scow in service. The next four columns denoted loading points, and were headed "Pier No. 72," "Thirty-third Street, East River," "Thirty-fifth Street, East River," and "Long Island City," respectively; the sixth column was headed "Greenville," the seventh "Hackensack," the eighth "Passaic," and the ninth "Governors Island," being unloading points, the tenth and eleventh, "Stake Boat" and "Dry Dock," respectively, while the twelfth was for "Extra pins," not in use. To indicate the condition of the scows, small pins with colored heads were used; white indicated empty; blue, working; black, loaded; red, being repaired; and a pearl-colored pin, missing. Thus a white-headed pin opposite the number 6 in the column headed Pier No. 72 indicated that scow No. 6 was lying at that pier waiting to be placed in position for

loading, whereas a black-headed pin at the same point meant that the scow had received its load and was ready to be towed.

The scows were all taken from the general service about the harbor; some of them were practically new, while others had seen much service. They were of two general types, truss-framed or bulkhead-framed; all were flat-bottomed, with a rake of about 45° at bow and stern. The truss-framed scows were built with a cross-truss every 10 to 15 ft., on which rested, fore and aft, two classes of beams, main and intermediate. The main beams were built of timbers ranging from 10 by 10 in. to 14 by 14 in., were scarfed at the joints, and trussed with the bottom logs. The intermediate beams were of timbers varying from

Scows.	Loading Points.				Unloading Points.				Stake Boat.	Dry Dock.	Extra Pins.
	Pier No. 72	Thirty-third Street East R.	Thirty-fifth Street East R.	Long Island City.	Greenville	Hackensack	Passaic.	Governors Island.			
H.S. No. 1											Empty.
H.S. No. 2											
H.S. No. 3											White Pins not in use placed here
H.S. No. 4											
H.S. No. 5											
H.S. No. 6											
H.S. No. 7											
H.S. No. 8											

BOARD
RECORDING LOCATION
AND CONDITION OF SCOWS

FIG. 10.

6 by 6 in. to 10 by 12 in., had butt joints, and were dapped at the cross-trusses to give a convex surface to the deck, which was built of 3-in. and 4-in. plank, from 8 to 12 in. in width, running athwartship. The sides of the scows of this class were spiked and bolted to trusses similar to those running under the main beams. The bulkheaded boats had both sides and two longitudinal bulkheads placed so as to divide the scow into three sections of equal width, built of 8 by 8-in. or 10 by 10-in. timbers, laid one upon the other, and bolted through from top to bottom. The beams on these boats ran athwartship, rested on sides and bulkheads, and ranged from 6 by 10-in. to 10 by 12-in., spaced 2 ft. apart, and dressed to give a convex surface to the deck, which

was usually 3 in., in some cases 4 in., in thickness, and made up of narrow plank from 4 to 6 in. in width.

These boats had all been designed for lighter work than they were here required to perform, and a large amount of breakage occurred from the start. In order that the contractors for the excavation should

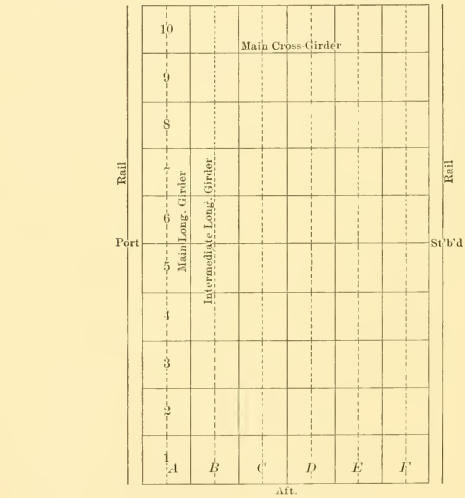


DIAGRAM OF DECK SHOWING BAYS
FIG. 11.

be unhampered as to method of loading, the contracts provided that they should pay for all damage done to the scows in loading, other than ordinary and usual wear and tear, all other damage being at the expense of the contractor for the disposal. A rigid system of inspection was necessary to determine and record properly the damage for which each contractor was responsible; and, as much of the breakage could not be noticed from the exterior, a thorough examination of the interior of each scow was made before and after every loading. In

order to keep proper records, the bays of each scow, formed by the cross-trusses, were numbered, beginning aft with number 1 and going forward to the bow, and the longitudinal bays formed by the main beams were lettered, beginning with *"A"* on the port side. A beam broken in "1-*A*," therefore, would be an intermediate beam in the stern port corner bay, and a beam broken in "10-*A*-*B*" would be a main beam at the bow end on the port side. The underside of each plank was marked with a number beginning with 1 at the stern and increasing by unity to the bow. Fig. 11 is a diagram of a scow in accordance with this system. In addition to recording the date, location, extent, and party responsible for each damage, in a book kept for that purpose, the injured member was marked with paint, the color of which indicated the party responsible. The repairs were made by the contractor for the disposal of material, and the cost was assessed according to the marking in the boat.

The careful inspection of the damage done to scows and the cost of their repairs enables a fairly accurate statement to be made of the amount at different points, and it is here given on the basis of cost of repairs per cubic yard, barge measurement, of material handled.

	Cost, in cents per cubic yard.
Repairs of damage done in loading material from the terminal site	2.00
Repairs of damage done in loading material from cross-town tunnels	1.32
Repairs of damage done in loading material from under-river tunnels	1.77
Repairs of damage done in transporting and unloading material from all points	1.81

The above figures do not include the expense due to scows which were overturned or sunk while in the service, which amounted to 0.4 cent per cubic yard, additional.

Ninth Avenue Tunnels.—The two double-track tunnels under Ninth Avenue, constructed to obtain 100 ft. of additional tail room on each of four tracks, required an excavation 76 ft. wide, Fig. 12. The rock, although fair, was not firm enough for so great a span, and, to obviate the necessity of timbering, the center wall was built before excavating

for the full width. The dip of the rock at this point is almost 90°, and to prevent blowing away the entire face in excavating for the tunnel, the pit excavation was not carried west to the final face below the springing line, a 10-ft. bench being left at that elevation. A top heading 9 ft. high and 10 ft. wide was started above that bench and, after penetrating about 10 ft., was widened to 20 ft. A cross-heading was driven in each direction at the west end of the first heading; the bench was then shot down, and the first 10 ft. of the longitudinal heading was widened sufficiently to receive the center wall, Fig. 12. After the middle wall had been concreted, any voids between its top and the rock

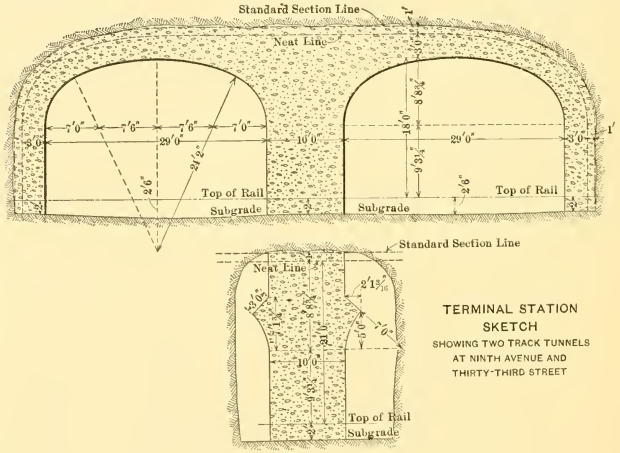


FIG. 12.

were grouted through pipes left for that purpose; the wall was then protected by curtains of heavy round timber securely wired together, and the remainder of the excavation was made by widening the cross-headings toward the face. The muck was carried out by two cableways, one on each side of the completed middle wall, each of which was supported by a tower outside of the tunnel and a large hook-bolt grouted into the rock at the inner end of the tunnel. Forms were built for each tunnel complete, and the concrete was delivered by a belt conveyor, running over the top of the lagging, and moved out as the tunnel was keyed.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1158

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE CROSS-TOWN TUNNELS.*

By James H. Brace and Francis Mason, Members, Am. Soc. C. E.

In this paper, it is proposed to describe the construction of the tunnels extending eastward from the easterly extension of the Terminal Station to the permanent shafts east of First Avenue.

They were located under 32d and 33d Streets from the station to Second Avenue, and thence, curving to the left, passed under private property and First Avenue to the shafts, as described in a preceding paper. Typical cross-sections of the tunnels are shown on Plate XII.†

On May 29th, 1905, a contract was entered into with the United Engineering and Contracting Company for the performance of this work. This contract provided that work on each pair of tunnels should be carried on from two shafts. The first, here referred to as the First Avenue Shafts, were located just east of that avenue and directly over the line of the tunnels; the other two, called the Intermediate Shafts, were located on private property to the north of each pair of tunnels in the blocks between Fourth and Madison Avenues. It was originally intended to do all the work of construction from these four shafts. Workings were started both east and west

* Presented at the meeting of December 1st, 1909.

† Of the paper by Mr. Noble.

from the Intermediate Shafts, and those to the west were to be continued to the Terminal Station. After the change of plans, described in a previous paper, it was decided to sink a third shaft on each line. These were known as the West Shafts, and were located between Sixth and Seventh Avenues. Finally, it was found necessary to build a portion of the tunnels on each line west of Sixth Avenue in open cut. The locations of the shafts are shown on Plate XIV.*

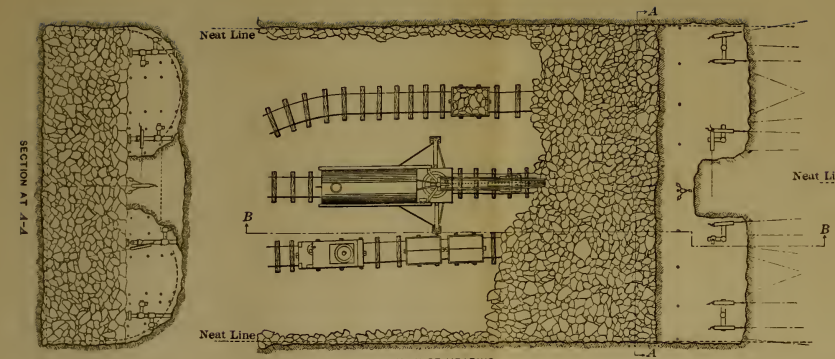
The First Avenue shafts were built by S. Pearson and Son, Inc., for the joint use of the two contractors, as described in the paper on the tunnels under the East River. While the shafts were being sunk, the full-sized tunnels were excavated westward by the contractor for the river tunnels for a distance of 50 ft., and top headings for 50 ft. farther. By this means, injury to the caissons and to the contractor's plant in the shafts by the subsequent work in the Cross-Town Tunnels was avoided. The west half of the shaft was for the exclusive use of the contractor for the Cross-Town Tunnels.

Contractor's Plant.

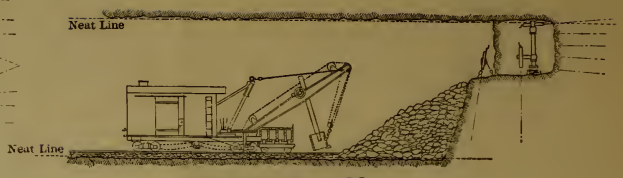
The method of handling the work adopted by the contractor was, broadly speaking, as follows: Excavation was usually carried on by modifications of the top-heading and bench method, the bench being carried as close to the face as possible in order to allow the muck from the heading to be blasted over the bench into the full section. The spoil was loaded into 3-yd. buckets (designed by the contractor and hereinafter described), by steam shovels operated by compressed air, and hauled to the shafts by electric locomotives. Electrically-operated telphers, suspended from a timber trestle, hoisted the buckets, and, traveling on a mono-rail track, deposited them on wagons for transportation to the dock. Arriving at the dock, the buckets were lifted by electrically-operated stiff-leg derricks and their contents deposited on scows for final disposal. The spoil was thus transported from the heading to the scow without breaking bulk.

When concreting was in progress, the spoil buckets were returned to the shafts loaded with sand and stone. The concrete materials were deposited in storage bins placed in the shafts, from which they were fed to the mixers located at the foot of the shaft about on a level with the crown of the tunnels. The concrete was transported to the forms in side-dump, steel, concrete cars, hauled by the electric locomotives.

* Of the paper by Mr. Noble.

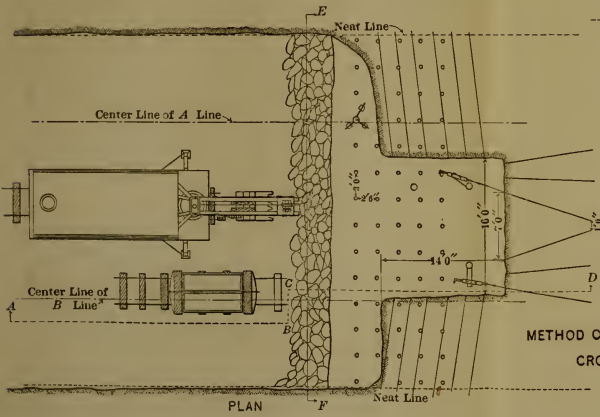


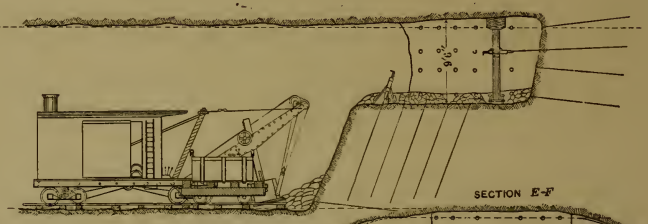
PLAN OF HEADING



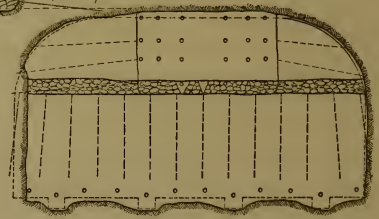
LONGITUDINAL SECTION AT *B-B*

EXCAVATION
WESTWARD FROM END OF ROCK DIVIDING WALL
TWIN TUNNELS *C* AND *D*

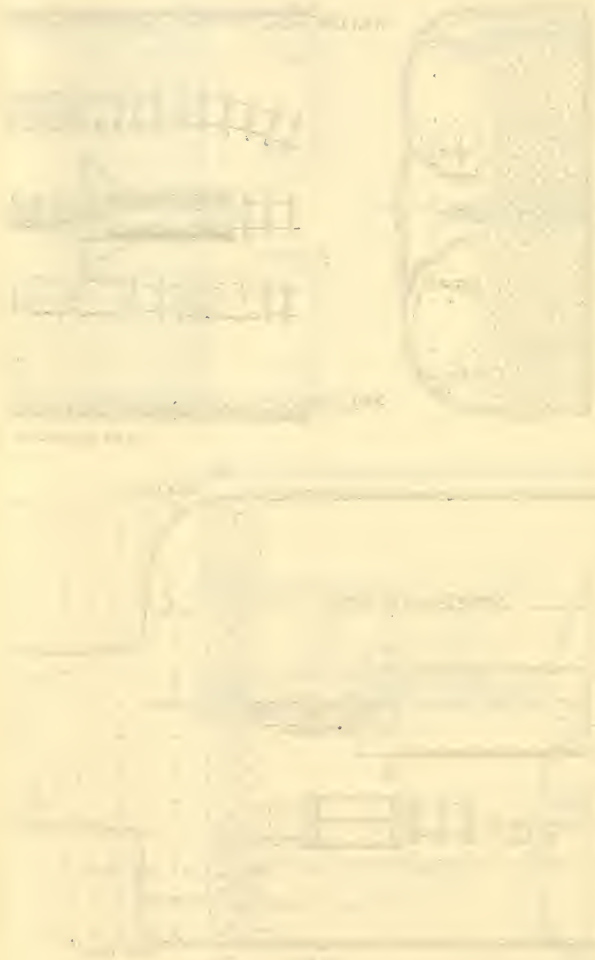




SECTION *A B C D*



A AND *B* TUNNELS
METHOD OF EXCAVATION WITH CENTER HEADING
CROSS-TOWN TUNNELS, MANHATTAN



Electrical power was adopted largely on account of the restricted area at the shaft sites, where a steam plant would have occupied considerable space of great value for other purposes. The installation of a steam plant at the Intermediate Shafts, which were located in a high-class residential district, would have been highly objectionable to the neighboring property owners, on account of the attendant noise, smoke, and dirt, and, in addition, the cost of the transportation of fuel would have been a serious burden. Except for the forges and, toward the last, the steam locomotives, not a pound of coal was burned on the work. The use of the bucket and telpher also eliminated most of the objectionable noise incident to the transfer of spoil from tunnel cars to ordinary wagons at the shaft sites. Power plants were installed at the North Shaft near First Avenue and at the rear of the 33d Street Intermediate Shaft.

First Avenue Plant.—Fig. 1, Plate LVIII, is a general view of the First Avenue plant. The power-house at the corner of 34th Street and First Avenue supplied compressed air for operating drills, shovels, pumps, and hoists in the tunnels driven from the river shafts, and in it three Laidlaw-Dunn-Gordon compressors were installed. The largest was a 32 by 20 by 30-in., two-stage, cross-compound, direct-connected to a Fort Wayne 480-h.p., 230-volt, direct-current, constant-speed motor run at 100 rev. per min. This compressor was rated at 2 870 cu. ft. of free air per minute at a pressure of 100 lb. It was governed by throttling the suction, the governor being controlled by the pressure in the air receiver and the motor running continuously at a constant speed. The two others were of similar type, one was 22½ by 14 by 18-in., rated at 1 250 cu. ft. of free air at a pressure of 100 lb., the other was 16 by 10 by 18-in., rated at 630 cu. ft. They were fitted with 9-ft. fly-wheels, and were driven at 150 rev. per min. by 105-h.p., General Electric, 220-volt, compound-wound, direct-current motors running at 655 rev. per min. The larger of these two compressors was driven by two of the motors belted in tandem, and the smaller was belt-connected to a third motor. The compressors were water-jacketed and had small inter-coolers, the water supply for which was itself cooled in a Wheeler Condenser and Engineering Company's water-cooling tower. The pump and the blower operating it were electrically driven.

The telphers, used for hoisting muck from the tunnels and for lowering supplies, were each hung from single rails on a timber trestle,

about 40 ft. high, spanning and connecting the two shafts. One machine was provided for each shaft, and where their tracks crossed 33d Street they were separated sufficiently to permit the machines to pass each other. At this point, and covering the street, a large platform was provided, on which the trucks were loaded and unloaded (Fig. 2, Plate LVIII), and from which they descended by an incline on First Avenue leading south to 32d Street. The platform also covered practically all the yard at the South Shaft and materially increased the available working area. The telphers were built by the Dodge Cold Storage Company, and were operated by a 75-h.p. General Electric motor for hoisting and a 15-h.p. Northern Electric Company motor for propulsion. Their rated lifting capacity was 10 000 lb. at a speed of 200 ft. per min.

The carpenter shop and machine-shop, both of which served the entire work, were conveniently located in small buildings on the loading platform. In the former the saws were each run independently by small electric motors suspended under the platform. The heavy forms and form carriages used in lining the tunnels with concrete were fabricated and stored on the platform outside. The machine-shop lathes, etc., were all belted to one shaft driven by an 8-h.p. General Electric motor. Above the machine-shop was a locker-room and below it on the street level was the main blacksmith shop for the work. Subsidiary blacksmith shops were located at each of the other shafts. The storeroom and additional locker-rooms were located above the power-plant in the North Shaft yard, and isolated from the other structures was a small oil-house. Additional storage space was provided by the contractor on 32d Street just west of First Avenue by renting three old buildings and the yards in the rear of them and of the Railroad Company's cement warehouse adjacent. Here electric conduits, pipe, castings, and other heavy and bulky supplies were stored.

During excavation the headings were supplied with forced ventilation through 12-in. and 14-in. No. 16, spiral-riveted, asphalted pressure pipes, canvas extensions being used beyond the ends of the pipes. A No. 4 American Blower, located at the top of each shaft and driven by a 15-h.p. General Electric motor, supplied the air.

A concrete-mixing plant was placed in each shaft, the mixer being located high enough to discharge into cars at about the level of the springing line of the arch. Above the mixers were the measuring

FIG. 1.—VIEW OF FIRST AVENUE PLANT.

FIG. 2.—TELPHER STRUCTURE AND LOADING PLATFORM, FIRST AVENUE SHAFT.

FIG. 3.—HEADWORKS AT 33D STREET: INTERMEDIATE SHAFT.

FIG. 4.—LOADING SPOIL ON BARGES, 35TH STREET PIER.

hoppers set in the floor of a platform which was large enough to carry half a day's supply of cement. At the South Shaft the cement was delivered to this floor from the loading platform through a spiral steel chute; at the North Shaft it was lowered in buckets by the telpher. The sand and stone were drawn into the hoppers through short chutes from the base of the storage bins which occupied the remaining height of the shaft—about 50 ft. At the South Shaft the bins were of concrete and steel, about 6 by 12 ft. in section, and attached to the central wall of the caisson. Sand and stone were delivered into them from dump-wagons on the loading platform. At the North Shaft steel-plate bins were used, and were supplied with material by the buckets handled by the telpher. The mixers were No. 5 Smith, belt-connected to 25-h.p. motors, and about 0.8 cu. yd. of concrete was mixed at a batch. The concrete cars were steel side-dumpers of the Wiener or Koppel type.

In order to be able to continue concreting during the winter, when neither sand nor stone could be obtained by water, practically all the space under the loading platforms in the South Shaft yards not occupied by the blacksmith shop was filled with these materials, which were placed in storage in the late fall.

Intermediate-Shaft Plant.—The air-compressing plant was located at the rear of the 33d Street Intermediate Shaft, and supplied air for driving the tunnels east and west from the Intermediate Shafts on both 32d and 33d Streets. Two compressors, the same as the large Laidlaw-Dunn-Gordon machine at First Avenue, were installed here, with a similar water-cooling tower.

Both shafts were on private property, owned by the Railroad Company, on the north side of the streets, and each was equipped with two telphers supported on timber trestles, similar to those at First Avenue. Here, however, the buckets were placed on wagons standing at the curb, as shown by Fig. 3, Plate LVIII.

Blowers for ventilation were installed at each shaft, as at First Avenue, and, after the excavation had proceeded some distance, small blacksmith shops, for sharpening drill steel and making minor repairs, were located in the tunnels near the shafts.

The concrete plant in each shaft was similar in arrangement to those at First Avenue, but the storage bins had wooden walls made of 2 by 4-in. and 2 by 6-in. scantling nailed flat on each other.

The contractor's office on 33d Street backed up against the 32d Street shaft site, and the basement was used as a storeroom for supplies for both shafts.

After the decision to do part of the work between Sixth and Seventh Avenues in open cut, an 8-in. air main was laid in 33d Street to the West Shafts, and air was supplied from the Intermediate Shaft for work on both streets in that neighborhood.

West-Shaft Plant.—West of Sixth Avenue, between 32d and 33d Streets and adjacent to the open-cut sections, the Railroad Company obtained from the Hudson and Manhattan Railroad Company the use of a large area from which the buildings had recently been removed, and gave the use of it to the contractor. This was of great value in prosecuting the west end of the work. The two West Shafts were located in the streets and were supplied with short timber trestles similar to those at the Intermediate Shafts. One telpher was taken from each of the Intermediate Shafts to operate at each of the West Shafts. In addition, a number of stiff-leg derricks were set up along the open-cut section, and were operated by Lidgerwood or Lambert air hoisting engines, or by electric motors, as circumstances dictated. A 15-ton Bay City locomotive crane was also used along part of the open-cut work on 32d Street.

Several concrete plants were installed at points along the open-cut section, and were moved from place to place, the same general arrangement being adopted as at the plants already described. No. 3 and No. 4 Ransome mixers were used, and were generally set up at about the level of the top of the arch. The sand and stone storage bins were made of scantlings spiked together, and were necessarily rather shallow on account of the proximity of the tunnels to the street surface.

Thirty-fifth Street Pier.—For the receipt and disposal of materials at the 35th Street pier, four stiff-leg derricks, operated by electric hoisting engines, were installed. Two were used in lifting the muck buckets from the wagons and dumping their contents on the scows for final disposal (Fig. 4, Plate LVIII); and the other two were fitted with clam-shell buckets for unloading sand and broken stone from barges and depositing the materials in large hoppers, from which they were drawn into wagons for transportation to the various concrete plants. A large part of the cement (all of which was supplied by the Railroad Company) was also unloaded at the 35th Street

pier and hauled directly to the work, the surplus being stored temporarily in the Company's cement warehouses on 32d, 33d and 35th Streets, near First Avenue, from which it was drawn as required. On the dock was located the main powder magazine, a small concrete structure. Considerable use was also made of neighboring piers for unloading electric conduits, lumber, steel, etc.

Tunnel Plant.—The spoil buckets, designed by D. L. Hough and George Perrine, Members, Am. Soc. C. E., were a novel feature of the

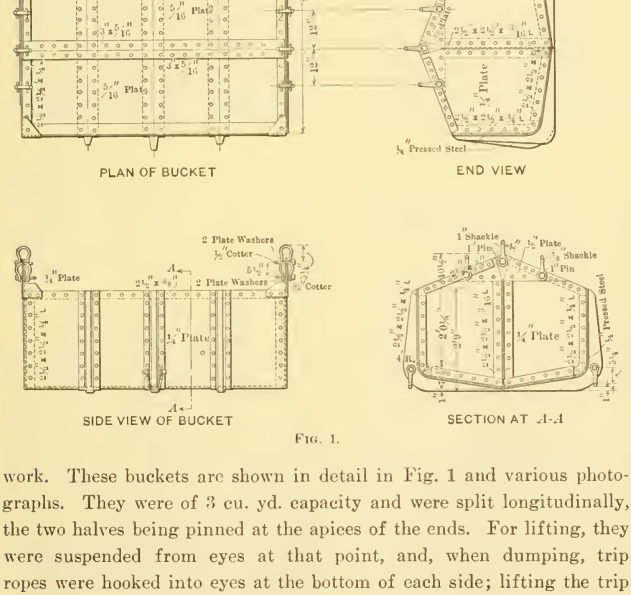


FIG. 1.

work. These buckets are shown in detail in Fig. 1 and various photographs. They were of 3 cu. yd. capacity and were split longitudinally, the two halves being pinned at the apices of the ends. For lifting, they were suspended from eyes at that point, and, when dumping, trip ropes were hooked into eyes at the bottom of each side; lifting the trip ropes or lowering the hoisting rope split the bucket, as shown in Fig. 4, Plate LVIII, and dumped the contents. They were transported in the tunnel on flat cars, and in the street on wagons, both cars and

wagons being provided with cradles shaped to receive the bottom of the bucket.

In the tunnels the loading was done with air-operated steam shovels, four (Model 20) Marion shovels being used at various points of the work. In Fig. 1, Plate LIX, one of these is shown loading the bucket. The cars were hauled by General Electric, standard, 10-ton, mine locomotives, the current for which was taken at 220 volts from a pair of No. 00 copper trolley wires suspended from the roof of the tunnel. The collector was a small four-wheeled buggy riding on the wires and connected to the locomotive by several hundred feet of cable wound on a reel for use beyond the end of the trolley wire. Two 8½-ton, Davenport, steam locomotives were also used in 32d Street, toward the end of the work, after the headings had been holed through and the tunnels would quickly clear themselves of gas and smoke. The steam shovels were supplemented by two Browning, 15-ton, locomotive cranes, which handled the spoil in places where timbering interfered with the operation of the shovels. All tracks were of 3-ft. gauge throughout and laid with 40-lb. rails.

Practically all the heavy drilling was done with Ingersoll drills (Model E 52), the trimming being largely done with jap and baby drills. A large number of pumps were used at various points on the work, and practically all were of Cameron make, the largest ones at the shaft being 10 by 5 by 13-in. The grout machines were of the vertical-cylinder, air-stirring type.

Shaft Sinking.

The sinking of the Intermediate Shafts was the first work undertaken by the contractor.

The 33d Street Shaft was 34.5 ft. long, 21 ft. wide, and 83 ft. deep. The rock surface averaged 5 ft. below the ground surface. Sinking was started on July 10th, 1905, and was completed on October 3d, 1905, the rock being hard and dry. The average daily rate was 0.73 ft. and an average of 17.1 cu. yd. were excavated per day, with two shifts of 8 hr. each. The first shift started at 6 A. M. and the second at 2.30 P. M., ending at 11 P. M. These hours were adopted in order to avoid undue disturbance during the night.

Before blasting the first lift of rock, channel cuts 5 or 6 ft. deep were made along the sides of the shaft, in order to avoid damage to the

FIG. 1.—AIR-OPERATED STEAM SHOVEL USED IN TUNNEL.

FIG. 2.—TIMBERING IN TOP HEADINGS ABOVE I-BEAMS.

FIG. 3.—FIRST SECTION OF CONCRETE LINING AT FIFTH AVENUE.

FIG. 4.—TIMBERING AND RUBBLE MASONRY OVER I-BEAMS.

walls of neighboring buildings. Timbering was required for a depth of only 10 ft. below the surface of the ground.

A drift, 30.6 ft. long, 17 ft. wide, and 27 ft. high, connected the south end of the shaft with the tunnels. The drift was excavated in three stages, a top heading and a bench in two lifts. While blasting the cut in the top heading, there was enough concussion to break glass in the neighboring buildings. The use of a radialax machine reduced the concussion somewhat, but it was very quickly abandoned on account of the length of time required for the drilling.

The construction of the 32d Street Shaft was quite similar to the one on 33d Street. It was 31.5 ft. long, 20.5 ft. wide, and 71 ft. deep. The depth of earth excavation averaged 19.5 ft. The rock in this shaft was seamy and not quite as hard or dry as that in 33d Street, and timbering was required for practically the full depth to the crown of the drift. Sinking was started on May 15th, 1905, and was completed on October 26th, 1905. The daily average rate was 0.30 ft. in earth and 0.52 ft. in rock. The drift was excavated in much the same manner as the one in 33d Street, but the rock being softer the radialax machine was not used.

Tunnel Excavation.

During the early part of the work, the contractor devoted his entire attention to the work of excavation. Nearly all the excavation east of Fifth Avenue was done before any of the lining was placed. At a number of points west of Fifth Avenue and at a few points to the east the nature of the rock was such that the two operations had to be done simultaneously.

Single-Tunnel Method.—For an average distance of 350 ft. west from the First Avenue Shafts there were four single tunnels. The rock was sound and comparatively dry. A top heading of the full size of the tunnel and about 8 ft. high was first driven. It was drilled by four drills mounted on two columns, and was blasted in the ordinary way. The bench was about 13 ft. high. Tripod drills, standing on the bench, drilled the usual holes, but, owing to the lack of head-room, steels long enough to reach the bottom of the bench could not be used. Tripod drills were set as low as possible at the foot of the bench and drilled lifting holes. These holes were inclined downward from 10° to 15° to the horizontal, and were spaced to converge at the location of the

drainage ditches. The heading was usually driven from 10 to 20 ft. in advance of the bench. At this distance a large part of the muck from the heading was shot backward over the bench. In the single tunnels the muck was loaded by hand.

Twin-Tunnel Methods.—From the end of the single-track tunnel westward to Fifth Avenue on 33d Street, and to Madison Avenue on 32d Street, with some exceptions, each pair of tunnels was excavated for the entire width at one operation. Three different methods of work were extensively used. They were the double-heading method, the center-heading method, and the full-sized-heading method, and these differed only in the manner of drilling and blasting. The bench was usually within 10 or 15 ft. of the face of the heading, and was drilled and fired in the same way as in the single tunnels. After the installation of the permanent plant, most of the muck was handled by steam shovels.

In the double-heading method, shown on Plate LVII, the top headings for each tunnel of the pair were driven separately, leaving a short rock core-wall between them. The headings were drilled from columns in the manner described for the single tunnels. The temporary rock dividing wall between the headings was drilled by a tripod drill on the bench of one of the headings, and was fired with the bench.

In the center-heading method, also shown on Plate LVII, only one heading was driven. It was rectangular in shape, about 8 ft. high and 14 ft. wide. It was located on the center line between the tunnels. In general, the face was from 6 to 12 ft., or the length of one or two rounds, in advance of the remainder of the face at the top. The center heading was drilled by four drills mounted on two columns. By turning these drills to the side, they were used for holes at right angles to the line of the tunnels, by which the remainder of the face of the heading was blasted. By turning the drills downward, the bench holes under the center heading were also drilled. The center heading explored the rock in advance of the full-width heading, and gave a good idea as to the care needed in firing.

For the full-width-heading method, Fig. 2, ten drills were mounted on five columns set abreast across the face. Holes were drilled to form a cut near the center line between the tunnels. The remainder of the holes were located so that they would draw into the cut. The bench was frequently drilled from the same set-up of columns by turning the

drills downward. In sound rock this method proved to be the most rapid of any.

Practically all trimming was left until immediately before the concreting. It was then taken up as a separate operation, but proved to be costly and tedious, and a hindrance to the placing of the lining.

Materials Encountered.—All the rock encountered was the familiar Hudson schist, but it varied widely in its mineral constituents and in its physical characteristics. In many places where the rock surface

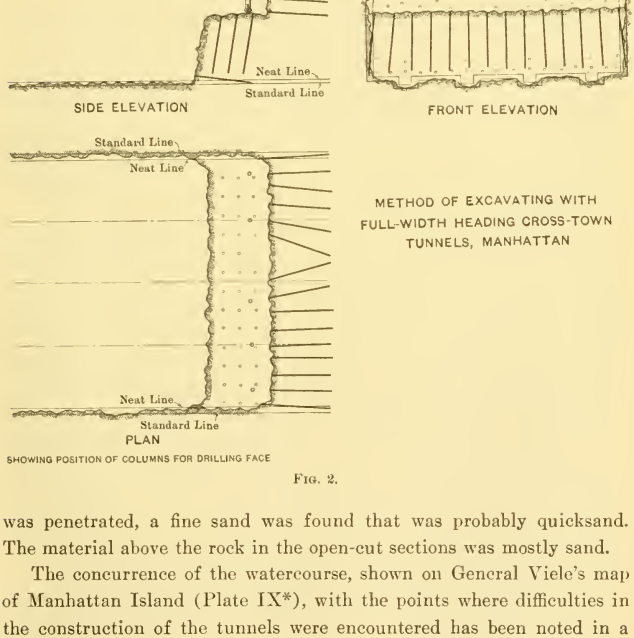


FIG. 2.

was penetrated, a fine sand was found that was probably quicksand. The material above the rock in the open-cut sections was mostly sand.

The concurrence of the watercourse, shown on General Viele's map of Manhattan Island (Plate IX*), with the points where difficulties in the construction of the tunnels were encountered has been noted in a previous paper.

* Of the paper by Mr. Noble.

In all cases where the course of this ancient stream was crossed (except at its final intersection of 33d Street), the rock was found to be very soft and disintegrated, a large quantity of water was encountered, and heavy timbering was required. The construction at these localities will be taken up later. In addition, disintegrated rock, but of a less troublesome character, was invariably met under the depressions in the rock surface developed by the borings from the streets and test holes from the tunnels. Many of these places required timbering, and no timbering was elsewhere necessary except at the portals. These coincident conditions were especially marked in 32d Street, which for a long distance closely adjoins the course of the former creek.

Disposal of Spoil.—The materials excavated from the tunnels were dumped at the 35th Street pier on barges furnished by the Railroad Company under another contract, and were towed to points near the Bayonne peninsula where the spoil was used principally in the construction of the Greenville Freight Yards and the line across the Hackensack Meadows to the tunnels. Details of this work will be given in a subsequent paper. After December, 1907, when the excavation was about 85% completed, the contractor furnished the barges and effected the complete disposal of the spoil.

Difficulties of Excavation.—As stated in a previous paper, the excavation of the Twin Tunnel in 33d Street was continued westward to the west line of Fifth Avenue on the original grade. At that point the contractor started three drifts in the three-track section. The relation of the drifts to each other and to the cross-section are shown by Fig. 3. The center heading was driven a little in advance of those on the sides. At a distance of 65 ft. west of Fifth Avenue the rock surface was broken through in the top of the heading, and a very fine sand was encountered. For some distance east of this point the rock was badly disintegrated, and the heading required timbering. Through the soft material, tight lagging was placed on the sides and roof of the heading, and the face was protected by breast boards. There was a moderate flow of water through the cracks, and, in spite of every effort, some of the fine sand was constantly carried into the heading.

In one or two instances considerable ground was lost at the face. On the evening of December 14th, 1906, as a heavy coal wagon was passing along 33d Street above the heading, the rear wheels dropped through the asphalt pavement. An examination disclosed a cavity

under the pavement about 14 ft. long, 12 ft. wide and 14 ft. deep. Evidently, the fine sand had gradually settled into the voids caused by the loss of material at the face, and the settlement broke the brick sewer over the heading. The sewer was temporarily repaired, and the hole in the street was filled before morning. A tight bulkhead was built acrosss the heading, and work was abandoned at that point. The north drift was advanced to a point 108 ft. west of Fifth Avenue where sand was also encountered and a considerable run occurred. After that time all work on the three-track section was discontinued.

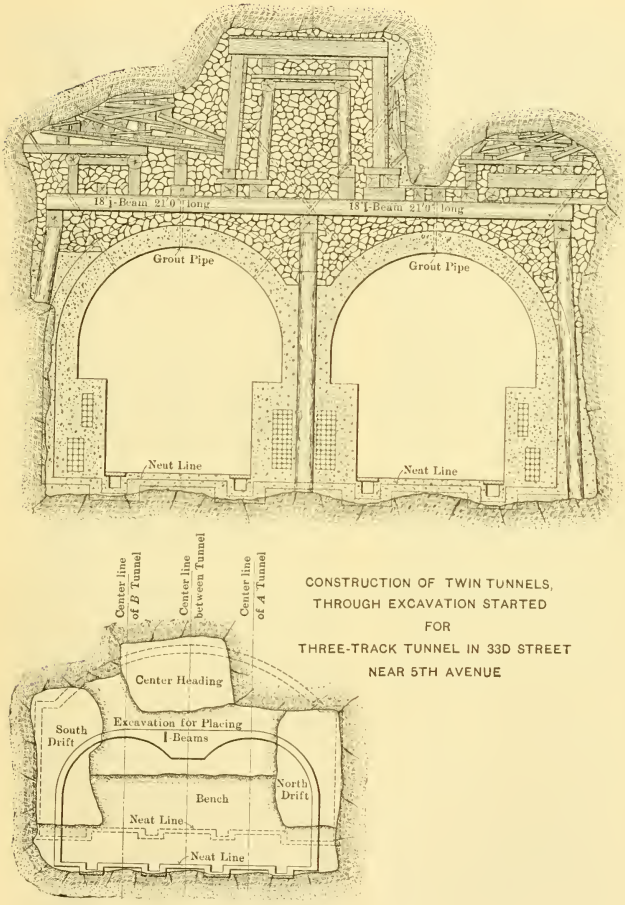
The Company then took up the consideration of changes in plan. To determine the difficulties of driving a Twin Tunnel at a lower elevation, an exploration drift, 8 ft. high and 12 ft. wide, was driven on the center line of the street as a top heading on the proposed new grade. Test holes were drilled above this heading and to the sides. The results indicated that there was sufficient rock cover of fair quality to enable the Twin Tunnel to be driven without great risk. The new plan (continuing the Twin Tunnel westward at a lower grade) was adopted in March, 1907, and work was immediately resumed at Fifth Avenue.

The relation between the cross-sections under the old and new plans at that point is shown by Fig. 3. Before the new section was excavated it was necessary to support the timber work in the old headings. The plan adopted is also shown by Fig. 3. The rock was excavated under the center heading, as shown in cross-section, for a length of about 3 ft. A girder composed of two 18-in. I-beams was then put in position over each line and supported on the sides by posts. The ends at the center lines between the tunnels were supported on short posts bearing on the rock bench. The support of the timbering in the headings was then transferred to the girders by additional posts. Blocking was also inserted between the tops of the beams and the rock walls between the headings Fig. 2, Plate LIX, gives a good idea of the timber work in the top headings above the I-beams. When the roof had been made secure, the removal of the bench was begun. As the work advanced it was necessary to replace the short posts at the center of the tunnel by others of full height, and there was considerable settlement in the I-beams during this operation. When the bench had been removed to a point 61 ft. west of Fifth Avenue, settlement was detected in the street surface above. Bench excavation was

suspended and a section of the permanent lining, 35 ft. long, was placed. The space between the lining and the beams and between the beams and the roof was filled with rubble masonry. Grout pipes were built into the masonry and later all voids were filled with grout. Fig. 3, Plate LIX, shows the first section of the concrete lining completed and part of the rubble in place; and Fig. 4, Plate LIX, shows details of the work above the tunnels. A second section of bench was next removed and more lining was placed. Work was continued in this way until all the roof at the old three-track headings had been secured. In this portion of the work the posts were embedded in the concrete.

Between Fifth and Sixth Avenues there were two more sections of bad rock where it was necessary to support the roof with steel beams. At these latter points there were no complications with the excavation for the Three-Track Tunnel, and the work was much simpler. To avoid leaving the center posts in the permanent work, two rows of temporary posts were placed, as shown by Fig. 1, Plate LX, the center wall and skewback were built, and the posts were removed, as shown by Fig. 2, Plate LX, before placing the remainder of the lining.

In 32d Street the normal progress of the excavation was frequently interrupted by encountering soft and unsound rock. In the excavation between the East River and the Intermediate Shafts it was possible to overcome these conditions by temporarily narrowing the excavation on one side and supporting the roof on 16 by 16-in. transverse timbers caught in niches in the rock at the sides, leaving sufficient room for the steam shovel to work through. In order to save time, the height of the excavation was not increased before placing these timbers, so that, previous to the concreting, they all required to be raised to clear the masonry lining and were then supported on posts on the center line between the tunnels. This permitted the remainder of the excavation to be made, and such additional timbering as was required was placed. At most of these sections a brick arch and water-proofing were used, on account of the presence of water. In certain places the center line posts were buried in the core-wall, and, in order to permit the placing of the water-proofing, were then cut off one by one flush with its top as the load was transferred to the completed masonry. In other cases the load was transferred to posts clear of the masonry and the center line posts were entirely removed. Under such conditions the normal



CONSTRUCTION OF TWIN TUNNELS,
THROUGH EXCAVATION STARTED
FOR
THREE-TRACK TUNNEL IN 33D STREET
NEAR 5TH AVENUE

FIG. 3.

concrete methods, to be described later, could not be used, and special forms were substituted.

In this section of the work the most serious difficulties were encountered near Fourth Avenue a short distance east of the Intermediate Shaft, and beneath the site of the old pond shown on General Viele's map. The rock cover was known from the boring to be very thin, and the presence of the subway overhead caused some anxiety. The excavation was at first taken out to practically full width and timbered, but the rock became so treacherous that the heading was narrowed to a width sufficient for one tunnel only. With this span the rock in the roof held without timbering. As the masonry lining approached, sufficient trimming was done to permit the placing of the core-wall and one arch. Above the completed core-wall and brick arch the voids were filled solid with rubble masonry to give an unyielding support to the roof. The excavation of the remaining width of tunnel was then undertaken. Near the west side of Fourth Avenue, the excavation broke out of rock at the top, and fine sand and gravel with a large quantity of water were encountered. The work of excavation was arduous, and proceeded very slowly, on account of the care with which it was executed. Only a small amount of sand entered the tunnel, but the lining was placed as soon as the excavation was completed. Rubble masonry packing and grout ejected through pipes built into the arch were used to fill the voids above the roof. As a further precaution against the settlement of the subway, 2-in. pipes were washed down from the street above the point where soft ground was exposed in the roof of the tunnel, and through them grout was forced into the ground at various depths. Careful levels show that no settlement of the subway has taken place.

West of the Intermediate Shaft the tunnel was excavated for full width until bad rock was encountered about 60 ft. west of Madison Avenue. (See General Viele's map, Plate IX.) Timbering was used for a short distance, and then the heading and bench were narrowed to 18 ft., and steam-shovel excavation was abandoned. As the heading advanced the rock grew steadily softer, the difficult conditions in this locality culminating when a slushy disintegrated feldspar was met, requiring poling and breasting. Thereafter the rock improved markedly, but near the east side of Fifth Avenue its thickness above

FIG. 1.—DOUBLE ROW OF POSTS UNDER I-BEAMS, SUPPORTING ROOF IN BAD ROCK SECTION.

FIG. 2.—CENTER WALL AND SKEWBACK UNDER I-BEAMS, AFTER REMOVAL OF DOUBLE ROW OF POSTS.

FIG. 3.—TIMBERING IN FULL-WIDTH HEADING OF THREE-TRACK TUNNEL.

FIG. 4.—UNDERPINNING WALLS IN OPEN-CUT SECTION.

the roof was found to be only 1½ ft., and the advance was stopped, pending a decision as to a change of plan.

After some delay, an exploration drift, similar to the one already described, was driven through to Sixth Avenue, and a change in plan was made, substantially the same as for the 33d Street tunnels. Enlargement to full size was at once started, but, for 400 ft. the rock was very soft and poor, and required extremely careful handling. The exploration drift was widened out to the full Twin-Tunnel width, and I-beams were placed and supported, in much the same manner as in 33d Street. The rock was so soft that it was frequently necessary to drive poling boards ahead as the face was mined out with picks and shovels. The load was very heavy, and the work the most difficult encountered in the tunnels.

After this stage of the enlargement was reached, the excavation of the bench and the placing of the lining proceeded alternately, with the I-beams temporarily supported on long posts while the concrete core-wall was being built. Considerable settlement took place while shifting the posts, and eventually showed on the street surface and in the adjacent sidewalk vaults, but no damage was done to the structural portions of the buildings.

While the above work had been going on westward from Fifth Avenue, the excavation of the Twin Tunnel eastward from the end of the open-cut section at Sixth Avenue had been proceeding rapidly, and, toward the end of the difficult Fifth Avenue work, it was being attacked from both directions.

Progress of Excavation.

Owing to the numerous sections of poor rock, interspersed throughout the work with stretches of sound rock, the progress of the excavation was very irregular, especially in 32d Street. The rate of excavation in good ground is shown in Table 1. In the sections of bad ground, the operations of excavation, timbering, and lining were often carried on alternately, and it is impracticable to include them in the table.

Three-Track Tunnel Excavation.

When it became evident that the work through the Fifth Avenue section would be extremely slow, shafts were sunk in each street

TABLE 1.—Progress and Methods

THIRTY-THIRD STREET.

Type of excavation.	Tunnels.	Worked from:	Dates. From	Dates. To
Full-sized single tunnel.....	B	1st Ave. shaft.	Feb. 28, 1906.	May 12, 1906.
Full-sized single tunnel.....	A	1st Ave. shaft.	Feb. 28, 1906.	Apr. 30, 1906.
Full-sized twin tunnel	A and B	1st Ave. shaft.	Aug. 23, 1906.	Jan. 5, 1907.
Full-sized twin tunnel	A and B	Intermediate shaft. (West of shaft.)	Apr. 4, 1906.	Oct. 31, 1906.
Full-sized twin tunnel	A and B	Intermediate shaft. (East of shaft.)	Apr. 4, 1906.	Oct. 31, 1906.
Full-sized twin tunnel	A and B	Intermediate shaft. (East of shaft.)	Nov. 1, 1906.	Dec. 26, 1906.
Exploration drift	A and B	Intermediate shaft (West of shaft.)	Mar. 1, 1907.	July 23, 1907.
Twin tunnel. Enlargement of exploration drift.....	A and B	West shaft (East of shaft.)	Sept. 6, 1907.	Dec. 4, 1907.

THIRTY-SECOND STREET.

Type of excavation.	Tunnels.	Worked from:	Dates. From	Dates. To
Full-sized single tunnel.....	C	1st Ave. shaft.	Jan. 25, 1906.	Apr. 30, 1906.
Full-sized single tunnel.....	D	1st Ave. shaft.	Jan. 27, 1906.	Apr. 30, 1906.
Full-sized twin tunnel	C and D	1st Ave. shaft.	May 22, 1906. Aug. 11, 1906.	July 24, 1906.* Nov. 29, 1906.
Narrowed twin tunnel.....	C	Intermediate shaft. (East of shaft.)	Mar. 19, 1906.	May 28, 1906.
Narrowed twin tunnel	C	Intermediate shaft. (East of shaft.)	May 29, 1906. July 18, 1906. Aug. 12, 1906. Jan. 15, 1907. Feb. 17, 1907.	July 3, 1906.* July 31, 1906. Nov. 23, 1906. Feb. 5, 1907. Mar. 21, 1907.
Full-sized twin tunnel	C and D	Intermediate shaft. (West of shaft.)	Dec. 1, 1905.	May 10, 1906.
Exploration drift	C and D	Intermediate shaft. (West of shaft.)	Feb. 1, 1907.	Sept. 13, 1907.
Twin tunnel. Enlargement of exploration drift...	C and D	Eastward from open cut.	Feb. 1, 1908.	Feb. 14, 1908.
Twin tunnel. Enlargement of exploration drift...	C and D	Eastward from open cut.	Feb. 15, 1908.	Apr. 14, 1908.

*Time and distance omitted while working through timbered stretches.

OF EXCAVATION IN GOOD GROUND.

Time elapsed, in days.	Length of tunnel excavated, in linear feet.	Average advance per day, in linear feet.	Methods and conditions.
74	316	4.7	Top heading and bench. Muck loaded by hand.
62	255	4.1	" " " " " " " "
136	789	5.8	Top full-width heading and bench. Muck loaded by steam shovel. Working exclusively on this heading.
210	730	3.5	Top center heading and bench. Muck loaded by steam shovel. Working alternately in headings east and west of the shaft.
210	783	3.7	Top center heading and bench. Muck loaded by steam shovel. Working alternately in headings east and west of the shaft.
56	311	5.5	Top full-width heading and bench. Muck loaded by steam shovel working exclusively on this heading.
145	947	6.5	Exploration drift about 9 ft. by 12 ft. Mucking by hand. Fourteen timber bents were placed in March, and seven in April, 1907.
89	603	6.8	Drift excavated to full width and bench. Muck loaded by steam shovel.
95	367	3.9	Top heading and bench. Muck loaded by hand.
93	354	3.8	" " " " " " " "
173	810	4.7	Double heading and bench. Muck loaded by steam shovel. Stretches aggregating 200 ft. narrowed to about 25 ft. and later enlarged are included.
70	58	0.8	Excavation about 30 ft. wide. Top full-width heading and bench. Muck loaded by hand. Steam shovel not installed.
208	1 206	5.8	Excavation about 30 to 35 ft. wide. Top full-width heading and bench. Muck loaded by steam shovel.
161	225	1.4	Double heading and bench. Part of the muck handled by hand and part by steam shovel.
225	1 033	4.6	Exploration drift about 10 ft. by 13 in. Muck loaded by hand. 14 ft. timbered.
14	65	4.6	At portal of twin tunnels. Drift excavated to full width and bench. Muck loaded by hand. 12 ft. timbered.
59	524	8.9	Drift excavated to full width and bench. Muck loaded by steam shovel. Full-width tunnel timbered for 26 ft. independently of the main excavation.

between Sixth and Seventh Avenues. The shafts, as shown on Plate XIV, were located in the streets, but in such a way as to block only half of the roadway. At the same time it was decided to construct in open cut about 200 ft. of the Three-Track Tunnel at the west end of the contract in 32d Street, where the rock surface was below the top of the tunnel. It was hoped that the remainder of the work could be built without opening the street, but further investigation showed that this was impracticable, and eventually all the Three-Track Tunnel in 32d Street, except 120 ft. east of the shaft, was built in open cut.

Thirty-second Street Work in Tunnel.—Following the sinking of the shaft, a drift was driven across the street at the crown of the tunnel, and a top heading on the south side was excavated in both directions. Frequent cross-drifts to the north side showed that the rock was nowhere very sound and that, except for a short distance east of the shaft, it was distinctly unfavorable for the wide Three-Track excavation. In this stretch the north ends of these cross-cuts were connected by a second heading, and wall-plates and sets of three-segment arch timbering were set up to support the roof of the drifts. The cross-cuttings were gradually widened and timbered until the entire excavation had been made down to the level of the wall-plates, as shown in Fig. 3, Plate LX. The bench was then excavated in two lifts, leaving the wall-plates supported on narrow longitudinal berms, which were removed in short sections to permit the placing of posts under the wall-plates.

Thirty-second Street Open-Cut Work.—Before actual open-cut excavation was started, all buildings facing it were underpinned to rock. For this purpose, a trench was dug along the face of the buildings and of the same depth as their cellars. Holes were cut in the front foundation walls through which long needle-beams (Fig. 4, Plate LX) were inserted and jacked up on blocking placed on the cellar floor and in the trench, until the weight of the building had been taken off its foundations. A close-sheeted trench was then sunk to rock under the front building walls, and a light rubble masonry retaining wall was built in it to support the building permanently. Frequently, the excavation for the underpinning wall, which was taken out in sections from 30 to 40 ft. long, and in places was carried to a depth of 40 ft., was very troublesome on account of the large quantity of water encountered and the fineness of the sand, which exhibited a tendency to flow when saturated.

The Elevated Railroad columns in Sixth Avenue, near the north and south lines of 32d Street, were underpinned in a manner similar to the building foundations, while those on the center line of the street were supported by girders riveted to them close under the track level. The girders in turn were supported on posts footed on the new underpinning of the adjacent columns. On the completion of the tunnels, concrete piers were built up from the roof of the tunnel to form a permanent foundation for the center-line columns. The area to be excavated under Sixth Avenue was enclosed by a rubble masonry retaining wall constructed in a trench.

Open-cut excavation was started by planking over the street on stringers resting on transverse 12 by 12-in. caps. The caps were gradually undermined and supported on temporary posts which were then replaced by short posts resting on 12 by 12-in. sills about 7 ft. below the cap. The operation was then repeated and the sill was supported on another set of short posts resting on a second sill. When the excavation had been carried down in this manner to the level of the top of the tunnel, diagonal 3 by 10-in. timbers were cut in between the posts and sills to form a species of double **A**-frame, the legs of which rested in niches cut in the rock and on posts carried up the face of the underpinning wall, and the whole was stiffened with vertical tie-rods. This construction is shown by Fig. 3, Plate LXII. The brick sewer was replaced temporarily by one of riveted steel pipe. This pipe and the water and gas pipes and electric conduits were suspended from the timbers as the pipes were uncovered.

Excavation in rock was made by sinking a pit to sub-grade for the full width of the tunnel and advancing the face of the pit in several lifts, the muck being blown over the slope and loaded into buckets at its foot.

The work was attacked at several places simultaneously, and the spoil was hoisted by derricks located at convenient points along the side of the cut.

Thirty-third Street Work in Tunnel and Open Cut.—The West 33d Street Shaft was similar to the one in 32d Street, and was sunk during February, March, and April, 1907, through 10 ft. of earth, 21 ft. of soft rock, and 29 ft. of fairly hard rock. It was necessary to timber heavily the upper 30 ft. of the shaft. The timber later showed evidences of severe strain, and had to be reinforced.

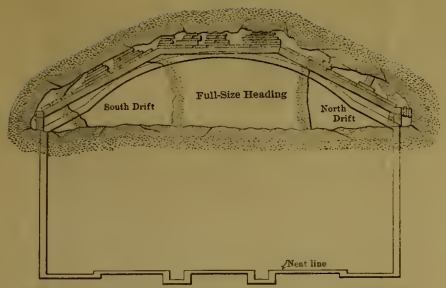
As soon as the shaft excavation was deep enough, a drift was

driven part way across the tunnels, and top headings were started both east and west to explore the rock. The heading to the west was divided into two drifts, as shown on Plate LXI. These two drifts were continued to the west end of the contract, and were then enlarged to a full-sized heading and timbered, as shown on Plate LXI and Fig. 3, Plate LX. The rock near the shaft contained many wet rusty seams, and settlement was detected in the segmental tunnel timbering soon after the widening of the heading was completed. Short props were placed under the timbers, and the street surface was opened with a view of stripping the earth down to the rock and thus lightening the load on the timbering. Street traffic was maintained on a timber structure with posts eventually carried down to the rock surface, and the walls of the buildings on the north side of the street were underpinned to rock. The settlement of the tunnel timbering was checked for a time, and the bench was excavated as shown on Plate LXI. In this work the cut in the center was first made, and the short props were replaced by struts, as shown; after this the berms were removed and the side posts were placed. While building the brick arches, holes were left in the masonry around the struts. After the masonry had hardened, piers were built on the arches to support the segmental timbers. The struts were then removed and the openings filled with masonry. The voids above the arch were packed with rock and afterward thoroughly grouted.

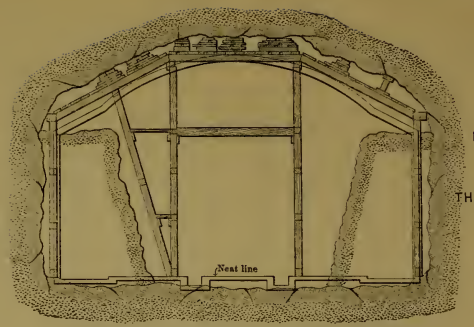
The timbers near the shaft continued to settle, and, although they had been placed from 9 to 12 in. above the level of the top of the masonry, by October 1st, they encroached 9 in. within the line of masonry. It was then decided to remove the rock for a distance of 48 ft. west of the shaft, and build this portion of the tunnel in open cut. The posts supporting the deck forming the street surface were replaced by an **A**-frame structure similar to that developed for the 32d Street open cut, without interruption of the street traffic.

After making the open cut to the westward of the shaft, there was a slip in the rock north of and adjoining the shaft. Fortunately, the timbers did not give way entirely, and no damage was done. The open cut was extended eastward for a distance of 46 ft., making the total length of tunnel built in open cut on this street 94 ft.

East of the shaft, for a distance of about 125 ft., the rock was broken and could not be excavated to full size without timbering the roof, but between this section of poor rock and those already men-



SECTION SHOWING NORTH AND SOUTH HEADING, ALSO ENLARGEMENT TO SINGLE HEADING AND METHOD OF TIMBERING



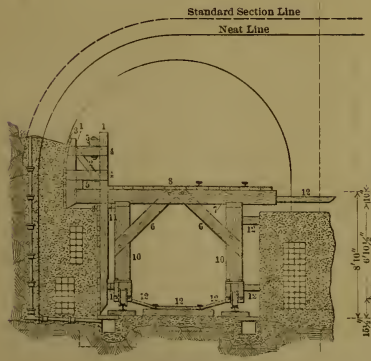
METHOD OF EXCAVATING BENCH, SHOWING CENTER EXCAVATION WITH TIMBERING ALSO ENLARGEMENT TO FULL SIZE AND TIMBERING

EXCAVATION AND TIMBERING IN HEAVY GROUND OF THREE-TRACK TUNNEL OF 33D ST.

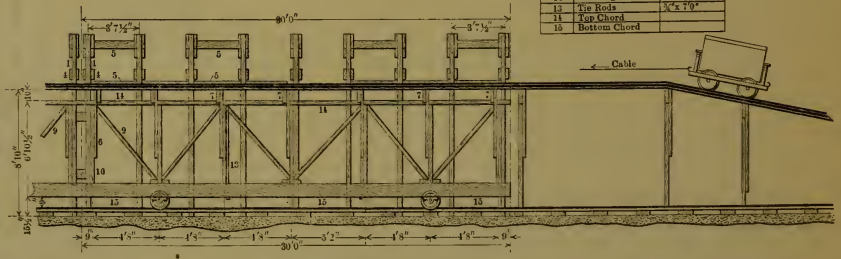
CARRIAGE FORM FOR SIDE WALLS OF CROSS-TOWN TWIN TUNNELS

Description

Piece	Location	Size
1	Studs	4"x 8"
2	Diagonals	4"x 6"x 3'
3	Lagging	2" dressed 16"lg
4	Braces (oak)	2"x 3"x 3'
5	Jacking Timbers	6"x 6"
6	Knee Braces	2"x 10"x 6'6"
7	Floor Joists	3"x 12"x 11'6"
8	Flooring	2"x 10"
9	Diagonal Braces	3"x 6"
10	Posts	3"x 12"
11	Wedges	
12	Braces (pine)	
13	Tie Rods	¾"x 1'0"
14	Top Chord	
15	Bottom Chord	



CROSS-SECTION



LONGITUDINAL SECTION ON C. L. OF CARRIAGE

tioned in connection with the work at Fifth Avenue, there was a stretch of 600 ft. of good rock where all the spoil was handled with a steam shovel.

Twin-Tunnel Lining.

The masonry lining for the tunnels was not started until the late fall of 1906, after excavation had been in progress for a year and a half. At that time concreting was started in the single tunnels westward from the First Avenue Shafts, and by spring was in full swing in the Twin Tunnels.

The plans contemplated the use of a complete concrete lining except where large quantities of water were encountered; in which case the arches, beginning at a point 15° above the springing line, were to be built of vitrified paving brick. By reference to Plate XII it will be seen that the water-proofing, which in the concrete-roof tunnels extended the full height of the sides to the 15° line, was carried in the brick-roof tunnels completely around the extrados of the arch. The cross-sections also show the location of the electric conduits which were buried in the mass of the side and core-walls and which limited the height to which the concrete could be carried in one operation.

The same general scheme of operations was used wherever possible throughout the Twin-Tunnel work, but was subject to minor modifications as circumstances dictated. Concrete was first deposited in the bottom, to the grade of the flow line of the drains; after it had set, collapsible box forms, of 2-in. plank with 3-in. plank tops, were laid on it to form the ditch and the shoulders for the flagstone covers. The track, which had previously been blocked up on the rock between the ditches, was raised and supported on the ditch boxes above the finished floor level. At the same time, light forms were braced from the ditch boxes to the grade of the base of the low-tension and telephone-duct bank. After depositing the concrete to this level, the telephone ducts were laid.

The forms for the water-proofing or sand-wall up to the 15° line and for the main side-walls and core-walls were built in 30-ft. panels and were supported on carriages, which, traveling on a broad-gauge track above the ditches, moved along the tunnel, section by section, as the work advanced. The panels were hung loosely from joists carrying a platform on the top chord of the carriage trusses, and were

adjusted transversely by bracing and wedging them out from the carriage. The small forms for the refuge niches, ladders, etc., were collapsible, and were spiked to the main panel forms just previous to the deposition of the concrete. The concrete was deposited from the platform on top of the carriage, to which the cars were elevated in various ways. Plate LXI shows the details of the carriages, and is self-explanatory.

The concrete for the sand-walls and the core-wall, to the level of the sidewalk, was deposited at the same time; two carriages in each tunnel, placed opposite each other, forming a 60-ft. length, were used at each setting. The floor section of the 4-in. tile drains had been laid with the floor concrete, and, as the sand-wall concrete was deposited, the drains were brought up simultaneously, broken stone being deposited between the tile and the rock to form a blind drain and afford access to the open joints of the tile for the water entering the tunnel through seams in the rock. The drains were spaced at intervals not exceeding 25 ft., depending on the wetness of the rock, and were placed at similar intervals in the core-wall under the lowest projecting points of the rock on the center line between the tunnels. A small ditch lined with loose 6-in. vitrified half pipe was provided in the top of the sand-wall to collect the water from the extrados of the arch and lead it to the top of the drains. Great difficulty was experienced in maintaining these drains clear, and, on completion of the work, a large amount of labor was expended in removing obstructions from the floor sections, the only portion then accessible.

After water-proofing the sand-walls and laying the low-tension ducts, a second pair of carriages, with panels on one side only, for 60 ft. of side-wall and skewback to the 15° line, were set and braced against the core-wall. These forms are shown in connection with the carriage on Plate LXI. They were concreted to the base of the high-tension duct bank, and, after the concrete had hardened and the bank of ducts had been laid, the concreting was completed in a second operation.

In places where the roof was supported temporarily by posts and heavy timbering, such as at Fifth Avenue, the form carriages could not be used, and special methods were devised to suit the local conditions. Usually, the panels were stripped from the carriages and moved from section to section by hand, and, when in position, were braced to the timbering.

The arch centers were built up of two 5 by 3 by §-in. steel angles, and, when set, were blocked up on the sidewalks opposite each other in the two tunnels. A temporary platform was laid on the bottom chord angles of the ribs, on which the concrete was dumped, the same as on the form carriages. The lagging used was 3 by 3-in. dressed pine or spruce 16 ft. long, and was placed as the concreting of the arch proceeded above the 15° line on the side-wall and above the sidewalk on the core-wall. After the arch had reached such a height that the concrete could not be passed over the lagging directly from the main platform, it was cast on a small platform on the upper horizontal bracing of the centers, shown in Fig. 3, Plate LIX, and was thence shoveled into the work. In the upper part of the arch the face of the concrete was kept on a radial plane, and, when only 3 ft. remained to be placed, it was keyed in from one end, the key lagging being set in about 5-ft. lengths. The arches were concreted usually in 60-ft. lengths.

Where brick arches were used, the core-wall skewback was concreted behind special forms set up on the sidewalks, or the arch ribs and lagging were used for forms, and the brick arch was not started until after the concrete had set. In laying the brick in the arch, the five courses of the ring were carried up as high as the void between the extrados and the rock would permit and still leave a working space in which to place the water-proofing. This was usually not more than 3 ft., except on the core-wall side. The felt and pitch water-proofing was then laid for that height, joined to the previous water-proofing on the side-walls, and was followed by the brick armor course over the water-proofing and by the rock packing, after which another lift of brick was laid and the operations were repeated. The large void (Fig. 1, Plate LXII) above the core-wall gave convenient access for working on top of the adjacent sides of the roof, and the keying of the arches and the water-proofing and rock packing above the core-wall were usually carried on from that point, the work progressing from one end.

The concrete for all work above the floor was dumped on the platform of the carriages, to which it was transported in the early part of the work in cars running on a high-level track laid on long ties, resting on the finished sidewalks. This arrangement, although requiring a large amount of timber for the track, permitted the muck to be carried out on the low-level track without interference. Later, when the

advance of the heading had ceased and the heavy mucking was over, all concrete was transported on the floor level, and the cars were lifted to the carriage platforms by elevators and were hauled by hoisting engines up a movable incline. The latter method is shown by Fig. 3, Plate LIX.

Water-Proofing.—The water-proofing referred to above was in all cases felt and pitch laid with six thicknesses of felt and seven of pitch. The sub-contractor for the work was the Sicilian Asphalt Paving Company. All joints were lapped at least 1 ft., and, where work was suspended for a time and a bevel lap could not be made, the edges of the felt were left unpitched for 1 ft. and the newer work was interlaced with the old. This method was not always successful, however, on account of the softening of the unpitched felt on long-continued exposure to the water. The felt used was mainly "Tunaloid," together with some "Hydrex." It weighed about 12 lb. per 100 sq. ft. when saturated and coated on one side only, and contained about 25% of wool. The coal-tar pitch used had a melting point of 100° Fahr.

After the completion of the tunnel, the concrete arch showed some leakage and in places unsightly lime deposits. It was determined to attempt to stop these leaks by the application of a water-proof cement coating on the intrados of the arch. Extended experimental application of two varieties of materials used for this purpose—"Hydrolithic" cement and the U. S. Water-proofing Company's compound—have been made with apparent success up to the present time, and the results after the lapse of a considerable period are awaited with interest.

Duct Laying.—The position of the electric conduits, buried in the heart of the concrete walls, interfered greatly with the economical and speedy placing of the lining, and their laying proved to be one of the most troublesome features of the work. The power conduits were single-way, with the bank for high-tension cables separated in the side-walls from the low-tension bank, as shown on Plate XII. The conduits for telephone and telegraph service were four-way, and were located in the core-wall. All ducts had $\frac{3}{4}$-in. walls and a minimum clear opening of $3\frac{3}{8}$ in. square, with corners rounded. They were laid with joints broken in all directions, and in about $\frac{1}{4}$-in. beds of 1:$2\frac{1}{2}$ mortar. Flat steel bond-irons, 2 by $\frac{1}{8}$ in., with split and bent ends, were placed in the joints at intervals of 3 ft. and projected into the concrete 3 in. on each side, tying together the concrete on opposite sides of the ducts. The joints were wrapped with a 6-in. strip of 10-oz.

FIG. 1.—WATER-PROOFING OVER BRICK ARCHES.

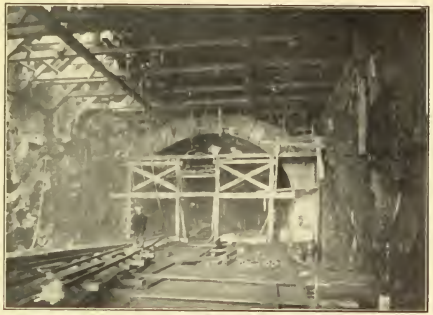


FIG. 2.—TRESTLE USED IN CONCRETING IN THREE-TRACK TUNNEL.

FIG. 3.—METHOD OF STREET SUPPORT OVER OPEN-CUT EXCAVATION.

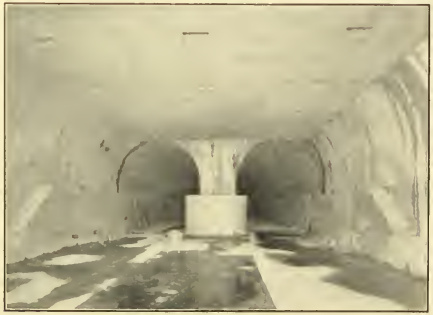


FIG. 4.—JUNCTION OF TWIN AND THREE-TRACK TUNNELS.

duck saturated with neat-cement grout, and, in addition, the power conduits were completely covered with a $\frac{1}{2}$-in. coat of mortar to prevent the intrusion of cement and sand from the fluid concrete. The four-way conduits were plastered only over the wraps. Splicing chambers were provided at intervals of 400 ft.

Three-Track Tunnel Lining.

In the Three-Track Tunnels, a heavy brick arch was used for those portions constructed in tunnel, while, in the open-cut sections, the roof was of concrete. Both were completely water-proofed on the roof and sides, and in the tunnel sections the space above the brick roof was filled with rock packing. On account of the unstable nature of the rock encountered throughout, the voids in the packing were afterward filled with grout.

By reference to the cross-sections, Plate XII, it will be seen that the haunches of the arch were tied together by steel I-beams anchored in the concrete, with the object of making the structure self-supporting in the event of the removal of the adjacent rock for deep cellar excavations. This construction materially influenced the contractor's method of placing the masonry lining.

After depositing the floor concrete, by the same method that was used in the Twin Tunnels, a timber trestle (Fig. 2, Plate LXII) was erected to the height of the underside of the I-beam ties, the posts being footed in holes, about 3 in. deep, left in the concrete floor to prevent slipping. In the open-cut sections the sand-wall forms were of undressed plank tacked to the studding and braced from the trestle; in the tunnel section they were spiked to the face of the posts supporting the timbering.

The side-wall forms were made up in panels about 3 by 10 ft., and were clamped to studs by U-shaped irons passing around the stud and bolted to the cleats on the back of the panels, the studs being braced from the trestle. The side-wall concrete was deposited in three sections. The first was brought up just above the sidewalk and formed the bench for the high-tension ducts; the second carried the wall up to the springing line. Before placing the third section the I-beam ties were set in position (Fig. 3, Plate LXII) on top of the trestle, and the reinforcing rods in the haunch of the arch were hung from them. The concrete was carried up to a skewback for the arch, as shown in the

brick-roof cross-section (Plate XII) and embedded the ends of the ties.

The centers for the arches stood on the I-beam ties, and the tops of the hangers, for the permanent support of the ties near their center, were inserted through the lagging. The brick arch, waterproofing, and rock packing were laid up in lifts, in the same manner as in the Twin Tunnel, with grout pipes built in at intervals of about 8 ft. The concrete arch was placed in sections, from 25 to 50 ft. in length, with a rather wet mixture and a back form on the steep slope of the extrados.

The concrete for the sand-walls and lower part of side-walls was handled on tracks and platforms laid on cantilever beams at mid-height of the trestle, as shown by Fig. 3, Plate LXII. For the walls above the springing line, the tracks were laid on top of the I-beam ties, and some of the arch concrete, also, was delivered from the mixer at that level and hauled up an incline to the level of the top of the arch. By far the greater part, however, was turned out from mixers set on the completed arch, and was transported on tracks hung in part from the street timbering.

Completion.—Except in the heavily-timbered portions, such as at Fifth Avenue, where the load had to be transferred from posts to the completed masonry section by section, the lining of the tunnels presented no special difficulty. The large number of small forms to be set, and the mutual interference of the concreting and duct-laying operations proved to be the most troublesome features of the work.

The restoration of the streets, public utilities, etc., at the open-cut sections was a slow and tedious operation, but the tunnels themselves were completed in March, 1909, 3 years and 10 months after the inception of the work. The finished tunnels are shown by the photograph, Fig. 4, Plate LXII, taken at the junction of the twin and three-track types.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1159

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE EAST RIVER TUNNELS.*

By James H. Brace, Francis Mason, and S. H. Woodard,
Members, Am. Soc. C. E.

This paper will be limited to a consideration of the construction of the tunnels, the broader questions of design, etc., having already been considered in papers by Brig.-Gen. Charles W. Raymond, M. Am. Soc. C. E., and Alfred Noble, Past-President, Am. Soc. C. E.

The location of the section of the work to be considered here is shown on Plate XIII of Mr. Noble's paper. There are two permanent shafts on each side of the East River and four single cast-iron tube tunnels, each about 6 000 ft. long, and consisting of 3 900 ft. between shafts under the river, and 2 000 ft. in Long Island City, mostly under the depot and passenger yard of the Long Island Railroad. This tube-tunnel work was naturally a single job. The contract for its construction was let to S. Pearson and Son, Incorporated, ground being broken on May 17th, 1904. Five years later, to a day, the work was finished and received its final inspection for acceptance by the Railroad Company.

The contract was of the profit-sharing type, and required an audit, by the Railroad Company, of the contractor's books, and a careful system of cost-keeping by the Company's engineers, so that it is possible to include in the following some of the unit costs of the work. These are given in two parts: The first is called the unit labor

* Presented at the meeting of December 15th, 1909.

cost, and is the cost of the labor in the tunnel directly chargeable to the thing considered. It does not include the labor of operating the plant, nor watchmen, yardmen, pipemen, and electricians. The second is called "top charges," a common term, but meaning different things to different contractors and engineers. Here, it is made to include the cost of the contractor's staff and roving laborers, such as pipemen, electricians, and yardmen, the cost of the plant and its operation, and all miscellaneous expenses, but does not include any contractor's profit, nor cost of materials entering permanent work.

The contractor's plant is to be described in a paper by Henry Japp,* M. Am. Soc. C. E., and will not be dealt with here.

The contractors carried on their work from three different sites. From permanent shafts, located near the river in Manhattan, four shields were driven eastward to about the middle of the river; and, from two similar shafts at the river front in Long Island City, four shields were driven westward to meet those from Manhattan. From a temporary shaft, near East Avenue, Long Island City, the land section of about 2 000 ft. was driven to the river shafts.

Tunnels from East Avenue to the River Shafts.

The sinking of the temporary shaft at East Avenue was a fairly simple matter. Rough 6 by 12-in. sheet-piling, forming a rectangle, 127 by 34 ft., braced across by heavy timbering, was driven about 28 ft. to rock as the excavation progressed. Below this, the shaft was sunk into rock, about 27 ft., without timbering. As soon as the shaft was down, on September 30th, 1904, bottom headings were started westward in Tunnels *A, B,* and *D*. When these had been driven about half the distance to the river shafts, soft ground was encountered. (See Station 59, Plate XIII.) As the ground carried considerable water, it was decided to use compressed air. Bulkheads were built in the heading, and, with an air pressure of about 15 lb. per sq. in., the heading was driven through the soft ground and into rock by ordinary mining methods. The use of compressed air was then discontinued. West of this soft ground, a top heading, followed by a bench, was driven to the soft ground at about Station 66. Tunnel *C,* being higher, was more in soft ground, and at first it was the intention to delay its excavation until it had been well drained by the bottom headings in

* *Transactions*, Am. Soc. C. E., Vol. LXIX, p. 1.

the tunnels on each side. A little later it was decided to use a shield without compressed air. This shield had been used in excavating the stations of the Great Northern and City Tunnel in London. It was rebuilt, its diameter being changed from 24 ft. 8½ in. to 23 ft. 5¼ in. It proved too weak, and after it had flattened about 4 in. and had been jacked up three times, the scheme was abandoned, the shield was removed, and work was continued by the methods which were being used in the other tunnels. The shield was rather light, but probably it would have been strong enough had it been used with compressed air, or had the material passed through been all earth. Here, there was a narrow concrete cradle in the bottom, with rock up to about the middle of the tunnel, which was excavated to clear the shield, and gave no support on its sides. The shield was a cylinder crushed between forces applied along the top and bottom.

With the exception of this trial of a shield in Tunnel *C*, and a novel method in Tunnel *B*, where compressed air, but no shield, was used, the description of the work in one tunnel will do for all.

From the bottom headings break-ups were started at several places in each tunnel where there was ample cover of rock above. Where the roof was in soft ground, top headings were driven from the points of break-up and timbered. As soon as the full-sized excavation was completed, the iron lining was built, usually in short lengths.

It will be noticed on Plate XIII that there is a depression in the rock between Station 65 and the river shafts, leaving all the tunnels in soft ground. As this was directly under the Long Island Railroad passenger station, it was thought best to use a shield and compressed air. This was done in Tunnels *A*, *C*, and *D*, one shield being used successively for all three. It was first erected in Tunnel *D* at Station 64 + 47. From there it was driven westward to the river shaft. It was then taken apart and re-erected in Tunnel *C* at Station 63+63 and driven westward to the shaft. It was then found that there would not be time for one shield to do all four lines. The experience in Tunnels *C* and *D* had proven the ground to be much better than had been expected. There was considerable clay in the sand, and, with the water blown out by compressed air, it was very stable. A special timbering method was devised, and Tunnel *B* was driven from Station 66+10 to the shaft with compressed air, but without a shield. In the meantime the shield was re-erected in Tunnel *A* and was shoved

through the soft ground from Station 65+48 nearly to the river shaft, where it was dismantled.

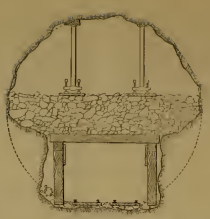
There was nothing unusual about the shield work; it was about the same as that under the river, which is fully described elsewhere. In spite of great care in excavating in front of the shield, and prompt grouting behind it, there was a small settlement of the building above, amounting to about 1½ in. in the walls and about 5 in. in the ground floors which were of concrete laid like a sidewalk directly upon the ground. Whether this settlement was due to ground lost in the shield work or to a compacting of the ground on account of its being dried out by compressed air, it is impossible to say.

The interesting features of this work from East Avenue to the river shafts are the mining methods and the building of the iron tube without a shield.

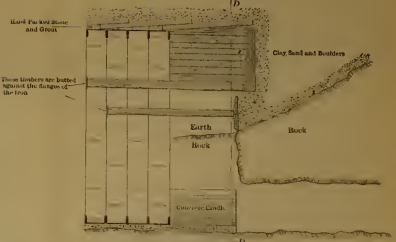
Excavation In All Rock.

Where the tunnel was all in good rock two distinct methods were used. The first was the bottom-heading-and-break-up, and the second, the top-heading-and-bench method. The first is illustrated by Figs. 1 and 2, Plate LXIII. The bottom heading, 13 ft. wide and 9 ft. high, having first been driven, a break-up was started by blasting down the rock, forming a chamber the full height of the tunnel. The timber platform, shown in the drawing, was erected in the bottom heading, and extended through the break-up chamber. The plan was then to drill the entire face above the bottom heading and blast it down upon the timber staging, thus maintaining a passage below for the traffic from the heading and break-ups farther down the line. Starting with the condition indicated by Plate XIII, the face was drilled, the columns were then taken down and the muck pile was shoveled through holes in the staging into muck cars below. The face was then blasted down upon the staging, the drill columns were set up on the muck pile, and the operation was repeated. This method has the advantage that the bottom heading can be pushed through rapidly, and from it the tunnel may be attacked at a number of points at one time. It was found to be more expensive than the top-heading-and-bench method, and as soon as the depression in the rock at about Station 59 was passed, a top heading about 7 ft. high, and roughly the segment of a 23-ft. circle, was driven to the next soft ground in each of the four tunnels. The remainder of the section was taken out in two

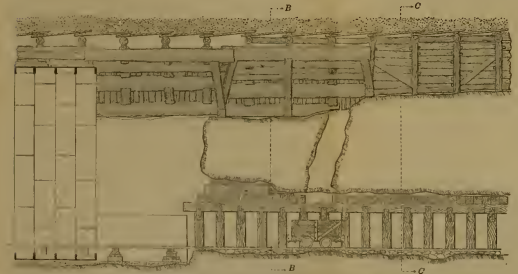
ENLARGING TUNNEL TO FULL SIZE-BOTTOM HEADING HAVING BEEN DRIVEN
FIG.1



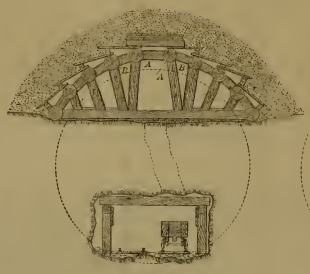
SECTION A-A
FIG.2



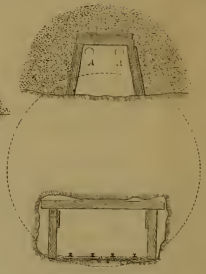
LONGITUDINAL SECTION
FIG.6



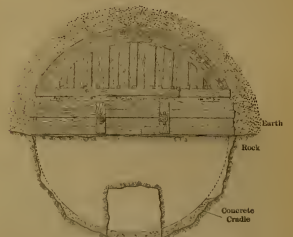
ENLARGING TO FULL SIZE, CROWN BARS IN POSITION
FIG.3



CROSS-SECTION B-B
FIG.4



CROSS-SECTION C-C
DRIVING TOP HEADING
FIG.5



CROSS-SECTION D-D
FIG.7

benches, the first, about 4 ft. high, was kept about 15 ft. ahead of the lower bench, which was about the remaining 11 ft. high.

Excavation in Earth and Rock.

About 2 500 ft. of tunnel, the roof of which was in soft ground, was excavated in normal air by the mining-and-timbering method. In the greater part of this the rock surface was well above the middle of the tunnel. The method of timbering and mining, while well enough known, has not been generally used in the United States.

Starting from the break-up in all rock, as described above, and illustrated on Plate XIII, when soft ground was approached, a top heading was driven from the rock into and through the earth. This heading was about 7 ft. high and about 6 ft. wide. This was done by the usual post, cap, and poling-board method. The ground was a running sand with little or no clay, and, at first, considerable water, in places. All headings required side polings. The roof poling boards were about $2\frac{1}{2}$ or 3 ft. above the outside limit of the tunnel lining, as illustrated by Figs. 3, 4, and 5, Plate LXIII. The next step was to place two crown-bars, *AA*, usually about 20 ft. long, under the caps. Posts were then placed under the bars, and poling boards at right angles to the axis of the tunnel were then driven out over the bars. As these polings were being driven, the side polings of the original heading were removed, and the earth was mined out to the end of these new transverse polings. Breast boards were set on end under the ends of the transverse polings when they had been driven out to their limit. Side bars, *BB*, were then placed as far out as possible and supported on raking posts. These posts were carried down to rock, if it was near, if not, a sill was placed.

A new set of transverse polings was driven over these side bars and the process was repeated until the sides had been carried down to rock or down to the elevation of the sills supporting the posts, which were usually about 4 ft. above the axis of the tunnel.

The plan then was to excavate the remainder of the section and build the iron lining in short lengths, gradually transferring the weight of the roof bars of the iron lining as the posts were taken out. This meant that not more than four rings, and often only one ring, could be built before excavation and a short length of cradle became necessary. Before the posts under the roof bars could be built and the

weight transferred to the iron lining, a grout dam was placed at the leading end of the iron lining, and grout was brought up to at least 45° from the top. Such workings were in progress at as many as eight places in one tunnel at the same time. Where there was only the ordinary ground-water to contend with, the driving of the top heading drained the ground very thoroughly, and the enlarging was done easily and without a serious loss of ground. Under these conditions the surface settlement was from 6 in. to 2 ft.

Under Borden Avenue, there was more water, which probably came from a leaky sewer; it was not enough to form a stream, but just kept the ground thoroughly saturated. There was a continued though hardly perceptible flow of earth through every crevice in the timbering during the six or eight weeks between the driving of the top heading and the placing of the iron lining; and here there was a settlement of from 4 to 8 ft. at the surface.

Tunneling in Compressed Air Without a Shield.

When it became evident that there would not be time for one shield to do the soft ground portions of all four tunnels under the Long Island Railroad station, a plan was adopted and used in Tunnel *B* which, while not as rapid, turned out to be as cheap as the work done by the shields. Figs. 6 and 7, Plate LXIII, and Fig. 1, Plate LXIV, illustrate this work fairly well. The operation of this scheme was about as follows: Having the iron built up to the face of the full-sized excavation, a hole or top heading, about 3 ft. wide and 4 or 5 ft. high, was excavated to about 10 ft. in advance. This was done in a few hours without timbering of any kind; but, as soon as the hole or heading was 10 ft. out, 6 by 12-in. laggings or polings were put up in the roof, with the rear ends resting on the iron lining and the leading ends resting on vertical breast boards. The heading was then widened out rapidly and the lagging was placed, down to about 45° from the crown. The forward ends of the laggings were then supported by a timber rib and sill. Protected by this roof, the full section was excavated, and three rings of the iron lining were built and grouted, and then the whole process was repeated.

Concrete Cradles, Hand-Packed Stone and Grouting.

Had the East Avenue Tunnel been built by shields, as was contemplated at the time of its design, the space between the limits of

PLATE LXIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1159.
BRACE, MASON, AND WOODARD ON
PENNSYLVANIA R. R. TUNNELS: EAST RIVER TUNNELS.

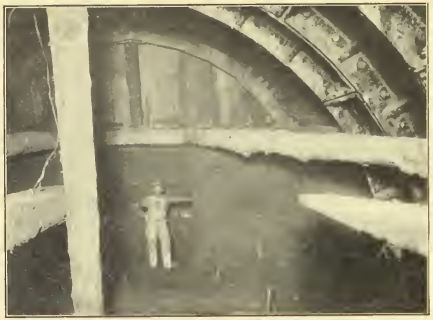


FIG. 1. TUNNELING IN COMPRESSED AIR WITHOUT SHIELD.

FIG. 2.—T-HEAD AIR-LOCK.

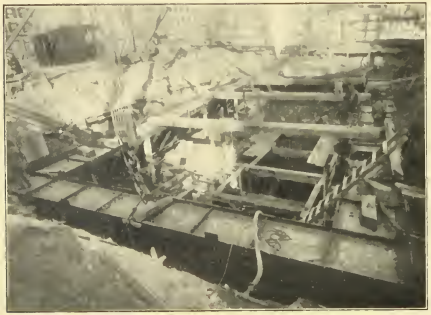


FIG. 3.—CUTTING EDGE OF CAISSON ASSEMBLED.

FIG. 4.—CAISSON SUPPORTED ON JACKS AND BLOCKS.

excavation and the iron lining would have been somewhat less than by the method actually used, especially in the earth portions. This space would have been filled with grout ejected through the iron lining. The change in the method of doing the work permitted the use of cheaper material, in place of part of the grout, and, at the same time, facilitated the work.

The tube of cast-iron rings is adapted to be built in the tail of the shield. Where no shield was used, after the excavation was completed and all loose rock was removed, timbers were fixed across the tunnel from which semicircular ribs were hung, below which lagging was placed. The space between this and the rough rock surface was filled with concrete. This formed a cradle in which the iron tube could be erected, and, at the same time, occupied space which would have been filled by grout, at greater cost, had a shield been used.

As soon as each ring of iron was erected, the space between it and the roof of the excavation was filled with hand-packed stone. At about every sixth ring a wall of stone laid in mortar was built between the lining and the rock to serve as a dam to retain grout. The interstices between the hand-packed stones were then filled with 1 to 1 grout of cement and sand, ejected through the iron lining. The concrete cradles averaged 1.05 cu. yd. per ft. of tunnel, and cost, exclusive of materials, $6.70 per cu. yd., of which $2.25 was for labor and $4.45 was for top charges. The hand-packed stone averaged 1½ cu. yd. per ft. of tunnel, and cost $2.42 per cu. yd., of which $0.98 was for labor and $1.44 was for top charges.

Erection of Iron Lining.

The contractors planned to erect the iron lining with erectors of the same pattern as that used on the shield under the river, mounted on a traveling stage. These will be described in detail in Mr. Japp's paper. Two of these stages and erectors worked in each tunnel at different points. The tunnel was attacked from so many points that these erectors could not be moved from working to working. The result was that about 58% of the lining was built by hand. At first thought, this seems to be a crude and extravagant method, as the plates weighed about 1 ton each and about 20 000 were erected by hand. As it turned out, the cost was not greater than for those erected by machinery, taking into account the cost of erectors and power. This, however,

was largely because the hand erection reduced the amount of work to be done by the machines so much that the machines had an undue plant charge.

The hand erection was very simple. A portable hand-winch, with a $\frac{5}{8}$-in. wire rope, was set in any convenient place. The wire rope was carried to a snatch-block fastened to the top of the iron previously built; or, where the roof was in soft ground, the timbering furnished points of attachment. The end of the wire rope was then hooked to a bolt hole in a new plate, two men at the winch lifted the plate, and three or four others swung it into approximate place, and, with the aid of bars and drift-pins, coaxed it into position and bolted it. Where there was no timbering above the iron, sometimes the key and adjoining plates were set on blocking on a timber staging and then jacked up to place.

Long Island Shafts.

The river shafts were designed to serve both as working shafts and as permanent openings to the tunnels, and were larger and more substantial than would have been required for construction purposes. Plate X of Mr. Noble's paper shows their design. They consist of two steel caissons, each 40 by 74 ft. in plan, with walls 5 ft. thick filled with concrete. A wall 6 ft. thick separated each shaft into two wells 29 by 30 ft., each directly over a tunnel. Circular openings for the tunnel, 25 ft. in diameter, were provided in the sides of the caissons. During the sinking these were closed by bulkheads of steel plates backed by horizontal steel girders. The shafts were sunk as pneumatic caissons to a depth of 78 ft. below mean high water. There have been a few caissons which were larger and were sunk deeper than these, but most large caissons have been for foundations, such as bridge piers, and have been stopped at or a little below the surface of the rock. The unusual feature of the caissons for the Long Island shaft is that they were sunk 54 ft. through rock.

It had been hoped that the rock would prove sound enough to permit stopping the caissons at or a little below the surface and continuing the excavation without sinking them further; for this reason only the steel for the lower 40 ft. of the caissons was ordered at first.

The roof of the working chamber was placed 7 ft. above the cutting edge. It was a steel floor, designed by the contractors, and consisted

of five steel girders, 6 ft. deep, 29 ft. long, and spaced at 5-ft. centers. Between were plates curved upward to a radius of 4 ft. Each working chamber had two shafts, 3 ft. by 5 ft. in cross-section, with a diaphragm dividing it into two passages, the smaller for men and the larger for muck buckets. On top of these shafts were Moran locks. Mounted on top of the caisson was a 5-ton Wilson crane, which would reach each shaft and also the muck cars standing on tracks on the ground level beside the caissons. Circular steel buckets, 2 ft. 6 in. in diameter and 3 ft. high, were used for handling all muck. These were taken from the bottom of the working chamber, dumped in cars, and returned to the bottom without unhooking. Work was carried on by three 8-hour shifts per day. The earth excavation was done at the rate of about 67 cu. yd. per day from one caisson. The rock excavation, amounting to about 6 200 cu. yd. in each caisson, was done at the rate of about 44.5 cu. yd. per day. The average rate of lowering, when the cutting edge of the south caisson was passing through earth, was 0.7 ft. per day. In rock, the rate was 0.48 ft. per day in the south caisson, and 0.39 ft. per day in the north caisson.

At the beginning all lowering was done with sixteen hydraulic jacks. Temporary brackets were fastened to the outside of the caisson. A 100-ton hydraulic jack was placed under each alternate bracket and under each of the others there was blocking. The jacks were connected to a high-pressure pump in the power-house. As the jacks lifted the caisson, the blocking was set for a lower position, to which the caisson settled as the jacks were exhausted. After the caisson had penetrated the earth about 10 ft., the outside brackets were removed and the lowering was regulated by blocking placed under brackets in the working chamber. The caisson usually rested on three sets of blockings on each side and two on each end. The blocking was about 4 ft. inside the cutting edge. In the rock, as the cutting edge was cleared for a lowering of about 2 ft., 6 by 8-in. oak posts were placed under the cutting-edge angle. When a sufficient number of posts had been placed, the blocking on which the caisson had rested was knocked or blasted out, and the rock underneath was excavated. The blocking was then re-set at a lower elevation. The posts under the cutting edge were then chopped part way through and the air pressure was lowered about 10 lb., which increased the net weight to more than 4 000 000 lb. The posts then gradually crushed and the caissons settled to the new block-

ing. The tilt or level of the caisson was controlled by chopping the posts more on the side which was desired to move first.

The caisson nearly always carried a very large net weight, usually about 870 tons. The concrete in the walls, which was added as the caisson was being sunk, was kept at about the elevation of the ground. There was generally a depth of from 5 to 20 ft. of water ballast on top of the roof of the working chamber. The air pressure in the working chamber was usually much less than the hydrostatic head outside the caisson. For example, the average air pressure in the south caisson during January, 1906, was 16½ lb., while the average head was 62.5 ft., equivalent to 27 lb. per sq. in. Under these conditions, there was a continued but small leakage into the caisson of from 15 000 to 20 000 gal. per day.

In the rock the excavation was always carried from 2 to 5 in. outside the cutting edge. As soon as the cutting edge was cleared, bags of clay were placed under it in a well-tiered, solid pile, so that when the caisson was lowered the bags were cut through and most of the clay, bags and all, was squeezed back of the cutting edge between the rock and the caisson.

Table 1 shows the relation of the final position of the caissons to that designed.

The cost of rock excavation in the caisson was $4.48 per cu. yd. for labor and $10.54 for top charges.

The bottom of the shaft is an inverted concrete arch, 4 ft. thick, water-proofed with 6-ply felt and pitch. As soon as the caisson was down to its final position and the excavation was completed, concrete was deposited on the uneven rock surfaces, brought up to the line of the water-proofing, and given a smooth 1-in. mortar coat. The felt was stuck together in 3-ply mats on the surface with hot coal-tar pitch. These were rolled and sent down into the working chamber, where they were put down with cold pitch liquid at 60° Fahr. Each sheet of felt overlapped the one below 6 in. The water-proofing was covered by a 1-in. mortar plaster coat, after which the concrete of the 4-ft. inverted arch was placed. While the water-proofing and concreting were being done, the air pressure was kept at from 30 to 33 lb. per sq. in., the full hydrostatic head at the cutting edge. After standing for ten days, the air pressure was taken off, and the removal of the roof of the working chamber was begun. The water-proofing was done by the Union Construction and Waterproofing Company.

TABLE 1.—Relation of the Final Position of the Caissons to That Designed.

Location.	Long Island City.						Manhattan.					
Shaft.	North.			South.			North.			South.		
Corner.	High.	East.	North.	High.	East.	North.	High.	East.	South.	High.	East or West.	North or South.
Northeast...	0.21 ft.	0.08 ft.	0.05 ft.	0.32 ft.	0.15 ft.	0.28 ft.	0.23 ft.	0.74 ft.	0.38 ft.	0.00 ft.	0.06 ft. east.	0.04 ft. south.
Northwest...	0.22 "	0.08 "	0.02 "	0.00 "	0.15 "	0.12 "	0.00 "	0.74 "	0.22 "	0.08 "	0.06 " "	0.13 " north.
Southwest...	0.27 "	0.14 "	0.02 "	0.18 "	0.45 "	0.12 "	0.11 "	0.31 "	0.22 "	0.21 "	0.45 " west.	0.13 " "
Southeast...	0.23 "	0.14 "	0.05 "	0.39 "	0.45 "	0.28 "	0.46 "	0.31 "	0.38 "	0.04 "	0.45 " "	0.04 " south.

The cost of labor in compressed air chargeable to concreting was $3.40 per cu. yd.

After the roof of each working chamber had been removed, the shield was erected on a timber cradle in the bottom of the shaft, in position to be shoved out of the opening in the west side of the caisson. Temporary rings of iron lining were erected across the shaft in order to furnish something for the shield jacks to shove against.

The roof of the working chamber was then re-erected about 35 ft. above its original position and about 8 ft. above the tunnel openings. This time, instead of the two small shafts which were in use during the sinking of the caisson, a large steel shaft with a T-head lock was built. This is illustrated in Fig. 2, Plate LXIV. The shaft was 8 ft. in diameter. Inside there was a ladder and an elevator cage for lowering and hoisting men and the standard 1-yd. tunnel cars. At the top, forming the head of the T, there were two standard tunnel locks.

Manhattan Shafts.

A permanent shaft, similar to the river shafts in Long Island City, was constructed at Manhattan over each pair of tunnels. Each shaft was located across two lines, with its longer axis transverse to the tunnels. Plate XIII shows their relative positions. They were divided equally by a reinforced concrete partition wall transverse to the line of the tunnels. On completion, the western portions were turned over to the contractor for the cross-town tunnels for his exclusive use.

South Shaft.—Work on the south shaft was started on June 9th, 1904, with the sinking of a 16 by 16-ft. test pit in the center of the south half of the south shaft, which reached disintegrated rock at a depth of about 20 ft.

Starting in August, the full shaft area, 74 by 40 ft., was taken out in an open untimbered cut to the rock, and a 20 by 50-ft. shaft was sunk through the rock to tunnel grade, leaving a 10 or 12-ft. berm around it. (Fig. 1, Plate LXX.)

The erection of the caisson was started, about the middle of January, on the rock berm surrounding the 20 by 50-ft. shaft and about 15 ft. below the surface. Fig. 3, Plate LXIV, shows the cutting edge of the caisson assembled. The excavation of the small

shaft had shown that hard rock and only a very small quantity of water would be encountered, and that the caisson need be sunk only a short distance below the rock surface. Therefore, no working-chamber roof was provided, the caisson was built to a height of only 40 ft., and the circular openings were permanently closed.

The assembling of the caisson took $2\frac{1}{2}$ months, and on April 2d lowering was started. Inverted brackets were bolted temporarily to the cutting-edge stiffening brackets, and the sinking was carried on by methods similar to those used at Long Island. The jacks and blocking supporting the caisson are shown in Fig. 4, Plate LXIV. As soon as the cutting edge entered the rock, which was drilled about 6 in. outside of the neat lines, the space surrounding the caisson was back-filled with clay and muck to steady it and provide skin friction. As the friction increased, the walls were filled with concrete, and as the caisson slowly settled, it was checked and guided by blocking. The cutting edge finally came to rest 31 ft. below mean high water, the sinking having been accomplished in about seven weeks, at an average rate of 0.50 ft. per day.

The final position of the cutting edge in relation to its designed position is shown in Table 1.

A berm about 4 ft. wide was left at the foot of the caisson below which the rock was somewhat fissured and required timbering. The cutting edge of the caisson was sealed to the rock with grout on the outside and a concrete base to the caisson walls on the inside, the latter resting on the 4-ft. berm. Following the completion of the shaft, the permanent sump was excavated to grade for use during construction.

North Shaft.—The north shaft had to be sunk in a very restricted area. The east side of the caisson cleared an adjoining building at one point by only 1 ft., while the northwest corner was within the same distance of the east line of First Avenue. As in the case of the Long Island shafts, the steelwork for only the lower 40 ft. was ordered at the start. This height was completely assembled before sinking was begun. The caisson was lowered in about the same manner as those previously described. The bearing brackets for the hydraulic jacks were attached, as at the south shaft, to the inside of the cutting-edge brackets. The east side of the caisson was in contact with the foundations of the neighboring building, while the west side was in much softer material. As a consequence, the west side tended to settle more

rapidly and thus throw the caisson out of level and position. To counteract that tendency, it was necessary to load the east wall heavily with cast-iron tunnel sections, in addition to the concrete filling in the walls.

Soon after sinking was begun, a small test shaft was sunk to a point below the elevation of the top of the tunnels. The rock was found to be sound, hard, and nearly dry. It was then decided to stop the caisson as soon as a foundation could be secured on sound rock. The latter was found at a depth of 38 ft. below mean high water. With the cutting edge seated at that depth, the top of the caisson was only 2 ft. above mean high water, and as this was insufficient protection against high tides, a 10-ft. extension was ordered for the top. Work, however, went on without delay on the remainder of the excavation. The junction between the cutting edge and the rock was sealed with concrete and grout. The caisson was lowered at an average rate of 0.53 ft. per day. The size of the shaft below the cutting edge was 62 ft. 7 in. by 32 ft. The average rate of excavation during the sinking in soft material was 84 cu. yd. per day. The average rate of rock excavation below the final position of the cutting edge was 125 cu. yd. per day. There were night and day shifts, each working 10 hours. Excavation in earth cost $3.96 per cu. yd., of which $1.45 was for labor and $2.51 for top charges, etc. The excavation of rock cost $8.93 per cu. yd., $2.83 being for labor and $6.10 for top charges.

The final elevations of the four corners of the cutting edge, together with their displacement from the desired positions, are shown in Table 1.

River Tunnels.

The four river tunnels, between the Manhattan and Long Island City shafts, a distance of about 3 900 ft., were constructed by the shield method. Eight shields were erected, one on each line in each shaft, the four from Manhattan working eastward to a junction near the middle of the river with the four working westward from Long Island City. Toward the end of the work it was evident that the shields in Tunnels *B*, *C*, and *D* would meet in the soft material a short distance east of the Blackwell's Island Reef if work were continued in all headings. In order that the junction might be made in firm material, work from Manhattan in those three tunnels was suspended when the shields

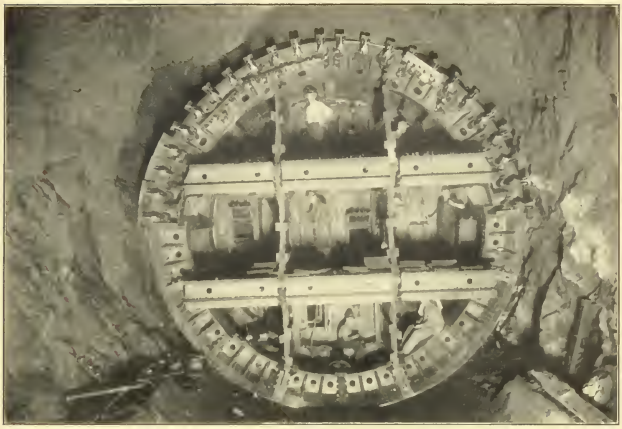


FIG. 1.—SHIELD FITTED WITH SECTIONAL SLIDING HOODS AND SLIDING EXTENSIONS TO THE FLOORS.

FIG. 2.—SHIELD FITTED WITH FIXED HOODS AND FIXED EXTENSIONS TO THE FLOORS.

reached the edge of the ledge. The shields in Tunnel *A* met at a corresponding point without the suspension of work in either. An average of 1 760 ft. of tunnel was driven from Manhattan and 2 142 ft. from Long Island City.

Tunnels Driven Eastward from Manhattan.

Materials and Inception of Work.—The materials encountered are shown in the profile on Plate XIII, and were similar in all the tunnels. In general, they were found to be about as indicated in the preliminary borings. The materials met in Tunnel *A* may be taken as typical of all.

From the Manhattan shaft eastward, in succession, there were 123 ft. of all-rock section, 87 ft. of part earth and part rock, 723 ft. of all earth, 515 ft. of part rock and part earth, 291 ft. of all rock, and 56 ft. of part rock and part earth.

The rock on the Manhattan side was Hudson schist, while that in the reef was Fordham gneiss. Here, as elsewhere, they resembled each other closely; the gneiss was slightly the harder, but both were badly seamed and fissured. Wherever it was encountered in this work, the rock surface was covered by a deposit of boulders, gravel, and sand, varying in thickness from 4 to 10 ft. and averaging about 6 ft.

The slope of the surface of the ledge on the Manhattan side averaged about 1 vertical to 4 horizontal. The rock near the surface was full of disintegrated seams, and was badly broken up. It was irregularly stratified, and dipped toward the west at an angle of about 60 degrees. Large pieces frequently broke from the face and slid into the shield, often exposing the sand. The rock surface was very irregular, and was covered with boulders and detached masses of rock embedded in coarse sand and gravel. The sand and gravel allowed the air to escape freely. By the time the shields had entirely cleared the rock, the material in the face had changed to a fine sand, stratified every few inches by very thin layers of chocolate-colored clayey material. This is the material elsewhere referred to as quicksand. As the shield advanced eastward, the number and thickness of the layers of clay increased until the clay formed at least 20% of the entire mass, and many of the layers were 2 in. thick.

At a distance of about 440 ft. beyond the Manhattan ledge, the material at the bottom of the face changed suddenly to one in which

the layers of clay composed probably 98% of the whole. The sand layers were not more than $\frac{1}{16}$ in. thick and averaged about 2 in. apart. The surface of the clay rose gradually for a distance of 40 ft. in Tunnels *A* and *B*, and 100 ft. in Tunnels *C* and *D*, when gravel and boulders appeared at the bottom of the shield. At that time the clay composed about one-half of the face.

The surfaces of both the clay and gravel were irregular, but they rose gradually. After rock was encountered, the formations of gravel and clay were roughly parallel to the rock surface.

As the surface of the rock rose they disappeared in order and were again encountered when the shields broke out of rock on the east side of the Blackwell's Island Reef. East of the reef a large quantity of coarse open sand was present in the gravel formations before the clay appeared below the top of the cutting edge. In Tunnels *C* and *D* this was especially difficult to handle. It appears to be a reasonable assumption that the layer of clay was continuous across the reef. Wherever the clay extended above the top of the shield it reduced the escape of air materially. It is doubtless largely due to this circumstance that the part-rock sections in the reef were not the most difficult portions of the work.

While sinking the lower portions of the shafts the tunnels were excavated eastward in the solid rock for a distance of about 60 ft., where the rock at the top was found to be somewhat disintegrated. This was as far as it was considered prudent to go with the full-sized section without air pressure. At about the same time top headings were excavated westward from the shafts for a distance of 100 ft., and the headings were enlarged to full size for 50 ft. The object was to avoid damage to the shaft and interference with the river tunnel when work was started by the contractor for the cross-town tunnel.

The shields were erected on timber cradles in the shaft, and were shoved forward to the face of the excavation. Concrete bulkheads, with the necessary air-locks, were then built across the tunnels behind the shields. The shields were erected before the dividing walls between the two contracts were placed. Rings of iron tunnel lining, backed by timbers spanning the openings on the west side, were erected temporarily across the shafts in order to afford a bearing for the shield jacks while shoving into the portals. The movement of the shield eastward was continued in each tunnel for a distance of about 60 ft.,

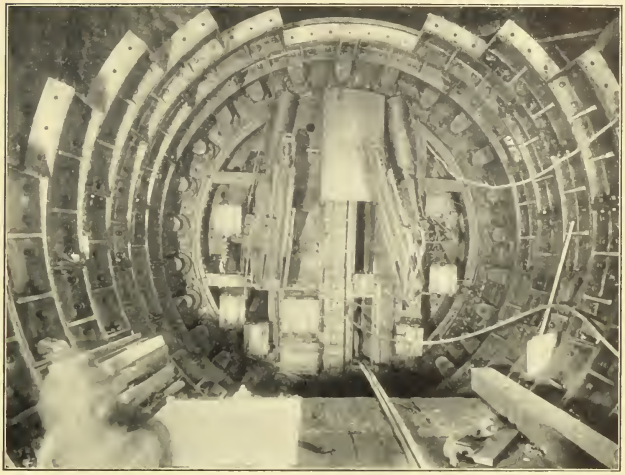


FIG. 1.—REAR OF SHIELD SHOWING COMPLETE FITTINGS.

FIG. 2.—SHIELD WITH LOWER PORTION OF BULKHEAD REMOVED.

and the permanent cast-iron tunnel lining was erected as the shield advanced. Before breaking out of rock, it was necessary to have air pressure in the tunnels. This required the building of bulkheads with air-locks inside the cast-iron linings just east of the portals. Before erecting the bulkheads it was necessary to close the annular space between the iron tunnel lining and the rock. The space at the portal was filled with a concrete wall. After about twenty permanent rings had been erected in each tunnel, two rings were pulled apart at the tail of the shield and a second masonry wall or dam was built. The space between the two dams was then filled with grout. To avoid the possibility of pushing the iron backward after the air pressure was on, rings of segmental plates, $\frac{5}{8}$ in. thick and $13\frac{1}{2}$ in. wide, were inserted in eighteen circumferential joints in each tunnel between the rings as they were erected. The plates contained slotted holes to match those in the segments. After the rings left the shield, the plates were driven outward, and projected about 5 in. When the tunnel was grouted, the plates were embedded.

The bulkheads were completed, and the tunnels were put under air pressure on the following dates:

Line *D*, on October 5th, 1905;
Line *C*, on November 6th, 1905;
Line *B*, on November 25th, 1905;
Line *A*, on December 1st, 1905.

This marked the end of the preparatory period.

In the deepest part of the river, near the pier-head line on the Manhattan side, there was only 8 ft. of natural cover over the tops of the tunnels. This cover consisted of the fine sand previously described, and it was certain that the air would escape freely from the tunnels through it. To give a greater depth of cover and to check the loss of air, the contractor prepared to cover the lines of the tunnels with blankets of clay, which, however, had been provided for in the specifications. Permits, as described later, were obtained at different times from the Secretary of War, for dumping clay in varying thicknesses over the line of work. The dumping for the blanket allowed under the first permit was completed in February, 1906. The thickness of this blanket varied considerably, but averaged 10 or 12 ft. on the Manhattan side. The original blanket was of material advantage, but the depth of clay was insufficient to stop the loss of air.

The essential parts of the shields in the four tunnels were exactly alike. Those in Tunnels *B* and *D*, however, were originally fitted with sectional sliding hoods and sliding extensions to the floors of the working chambers, as shown by Fig. 1, Plate LXV. The shields in Tunnels *A* and *C* were originally fitted with fixed hoods and fixed extensions to the floors, as shown in Fig. 2, Plate LXV. A full description of the shields will be found in Mr. Japp's paper.

The shields in each pair of tunnels were advanced through the solid rock section about abreast of each other, until test holes from the faces indicated soft ground within a few feet. As the distance between the sides of the two tunnels was only 14 ft., it was thought best to let Tunnels *B* and *D* gain a lead of about 100 ft. before Tunnels *A* and *C* opened out into soft ground, in order that a blow from one tunnel might not extend to the other. Work in Tunnel *C* was shut down on December 23d, 1905, after exposing sand to a depth of 3 ft. at the top, and it remained closed for seven weeks. Work in Tunnel *A* was suspended on September 29th, 1905. By the time Tunnel *B* had made the required advance, it, together with Tunnels *C* and *D*, was overtaxing the capacities of the compressor plant. Only a little work was done in Tunnel *C* until July, 1906, and work in Tunnel *A* was not resumed until October 22d, 1906.

Tunnels Driven Westward from Long Island City.

Materials and Inception of the Work.—The materials met in Tunnel *A* are typical of all four tunnels. From the Long Island shafts westward, in succession, there were 124 ft. of all-rock section, 125 ft. of part rock and part earth section, 22 ft. of all-rock section, 56 ft. of part rock and part earth section, 387 ft. of all-rock section, 70 ft. of part earth and part rock section, and 1 333 ft. of all-earth section.

The materials passed through are indicated on Plate XIII. The rock was similar to that of the Blackwell's Island Reef, and was likewise covered by a layer of sand and boulders. The remainder of the soft ground was divided into three classes. The first was a very fine red sand, which occurred in a layer varying in thickness from 6 ft. to at least 15 ft. It may have been much deeper above the tunnel. It is the quicksand usually encountered in all deep foundations in New York City. The following is the result of the sifting test of this sand:

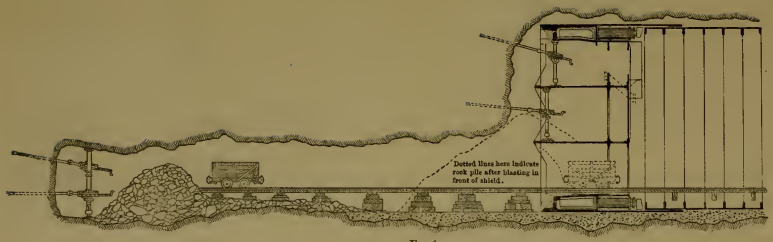
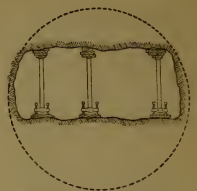


FIG. 1



SECTION AT *A-A*, FIG. 3 SHOWING
DRILL COLUMNS

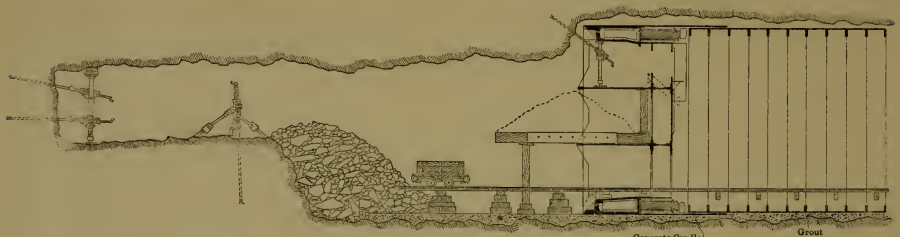
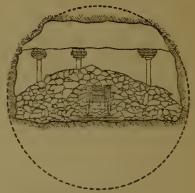


FIG. 2



CROSS-SECTION AT *B-B*, FIG. 3

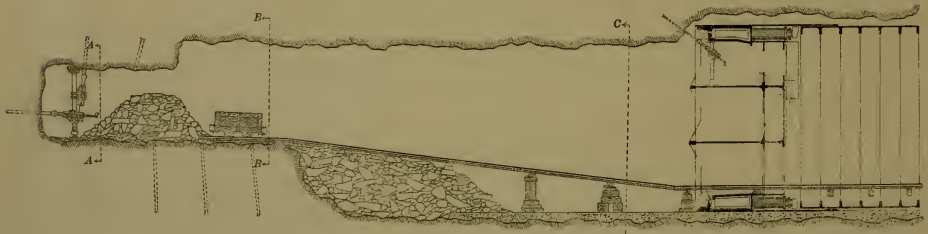


FIG. 3

CROSS-SECTION AT *C-C*, FIG. 3

		Held on	No.	30	sieve	0.6%
Passed	No. 30,	"	" No.	40	"	0.4%
"	No. 40,	"	" No.	50	"	0.7%
"	No. 50,	"	" No.	60	"	2.4%
"	No. 60,	"	" No.	80	"	14.9%
"	No. 80,	"	" No.	100	"	54.0%
"	No. 100,	"	" No.	200	"	8.0%
"	No. 200				"	19.0%
						100.0%

This means that grains of all but 4% of it were less than 0.0071 in. in diameter. The 19% which passed the No. 200 sieve, the grains of which were 0.0026 in. or less in diameter, when observed with a microscope appeared to be perfectly clean grains of quartz; to the eye it looked like ordinary building sand, sharp, and well graded from large to small grains. This sand, with a surplus of water, was quick. With the water blown out of it by air pressure, it is stable, stands up well, and is very easy to work. It appears to be the same as the reddish quicksand found in most deep excavations around New York City.

The second material was pronounced "bull's liver" by the miners as soon as it was uncovered. "Bull's liver" seems to be a common term among English-speaking miners the world over. It is doubtful, however, if it is always applied to the same thing. In this case it consisted of layers of blue clay and very fine red sand. The clay seemed to be perfectly pure and entirely free from sand. It would break easily with a clean, almost crystalline, fracture, and yet it was soft and would work up easily. The layers of clay varied in thickness from $\frac{1}{16}$ in. to 1 in., while the thickness of the sand layer varied from $\frac{1}{4}$ in. to several inches. The sand was the same as the quicksand already described.

The "bull's liver" was ideal material in which to work a shield. It stood up as well and held the air about as well as clay, and was much easier to handle.

The third material was a layer of fine gray sand which was encountered in the top of all the tunnels for about 400 ft. just east of Blackwell's Island Reef. It was very open, and had grains of rather uniform size.

During the starting out of the tunnels from the shafts, and for

more than a year afterward, the roof of the working chamber in the caissons and the locks previously described under the Long Island shafts took the place of the bulkhead across the tunnels for confining the air pressure.

The first work in air pressure was to remove the shield plug closing the opening in the side of the shaft. This being done, the shield was shoved through the opening, and excavation begun.

At the start the shields were fitted with movable platforms, but no hoods of any kind were placed until after the rock excavation was completed.

Methods of Excavation.

The distribution of materials to be excavated, as previously outlined, divided the excavation into three distinct classes, for which different methods had to be developed.

These three classes were:

First.—All-rock section.

Second.—Rock in the bottom, earth in the top.

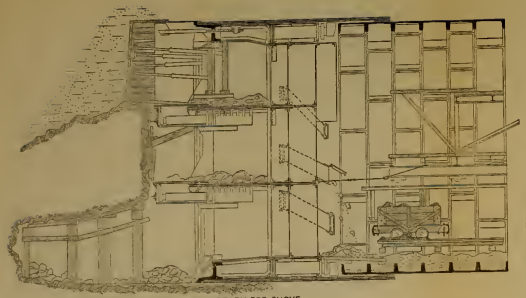
Third.—All-earth section.

The extent of the second and third classes was much greater than that of the first, and they, of course, determined the use of the shield. Shields had not previously been used extensively in rock work, either where the face was wholly or partly in rock, and it was necessary to develop the methods by experience. The specifications required that where rock was present in the bottom, a bed of concrete should be laid in the form of a cradle on which to advance the shield.

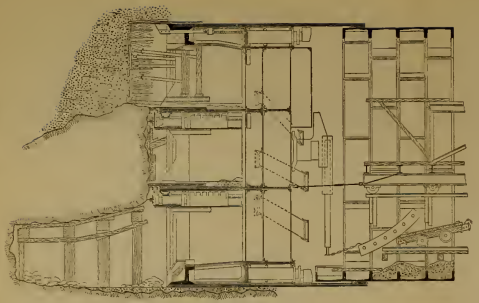
All Rock.—At different times, three general methods were used for excavating in all-rock sections. They may be called: The bottom-heading method; the full-face method; and the center-heading method.

The bottom-heading method was first tried. A heading, about 8 ft. high and 12 ft. wide, was driven on the center line, with its bottom as nearly as possible on the grade line of the bottom of the tunnel. It was drilled in the ordinary manner by four drills mounted on two columns. The face of the headings varied from 10 to 30 ft. in advance of the cutting edge. After driving the heading for about 10 ft., the bottom was cleared out and a concrete cradle was set. The width of the cradles varied, but was generally from 8 to 10 ft.

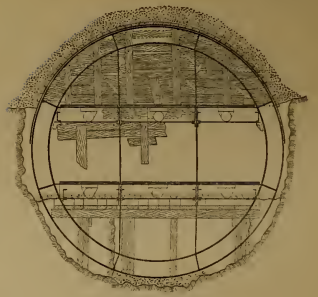
The excavation was enlarged to full size as the shield advanced, the drills being mounted in the forward compartments of the shield, as



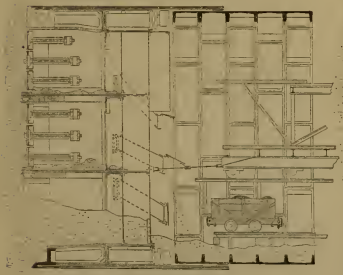
READY FOR SHOVE
FIG. 1.



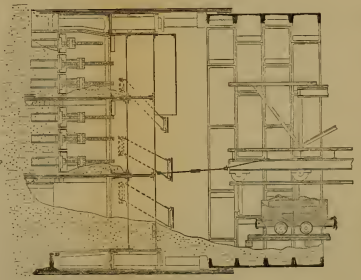
AFTER SHOVE, ERECTING IRON
FIG. 2



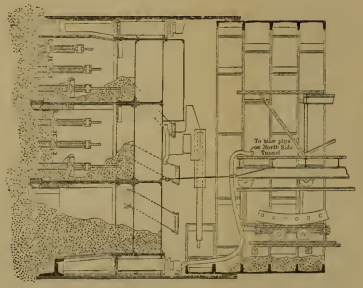
SECTION SHOWING BREASTING
FIG. 3



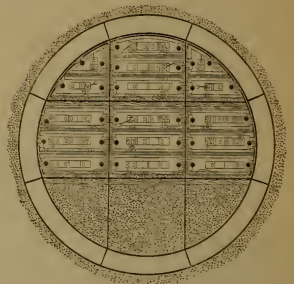
BEFORE SHOVE
FIG. 4.



AFTER SHOVE
FIG. 5.



PREPARING FOR 2D SHOVE AND PLACING BOTTOM PLATES
FIG. 6



BACK ELEVATION OF SHUTTERS, SHOWING SLIDES
FIG. 7

shown by Fig. 1, Plate LXVII, which represents the conditions after the opening had been cut in the bulkhead, but before the new methods, mentioned later, had been developed.

The sides and top were shot downward into the heading. The area of the face remaining behind the heading was large, and a great number of holes and several rounds were required to fire the face to advantage. As soon as firing was started at the face, the heading was completely blocked, and operations there had to be suspended until the mucking was nearly completed. The bottom-heading method was probably as good as any that could be devised for use with the shields as originally installed. All the muck had to be taken from the face by hand and handled through the chutes or doors. By drilling from the shield, some muck was blasted on to the extensions of the floors and could be handled from the upper compartments. At best, however, the shield with the closed transverse bulkhead was a serious obstacle to rapid work in rock sections.

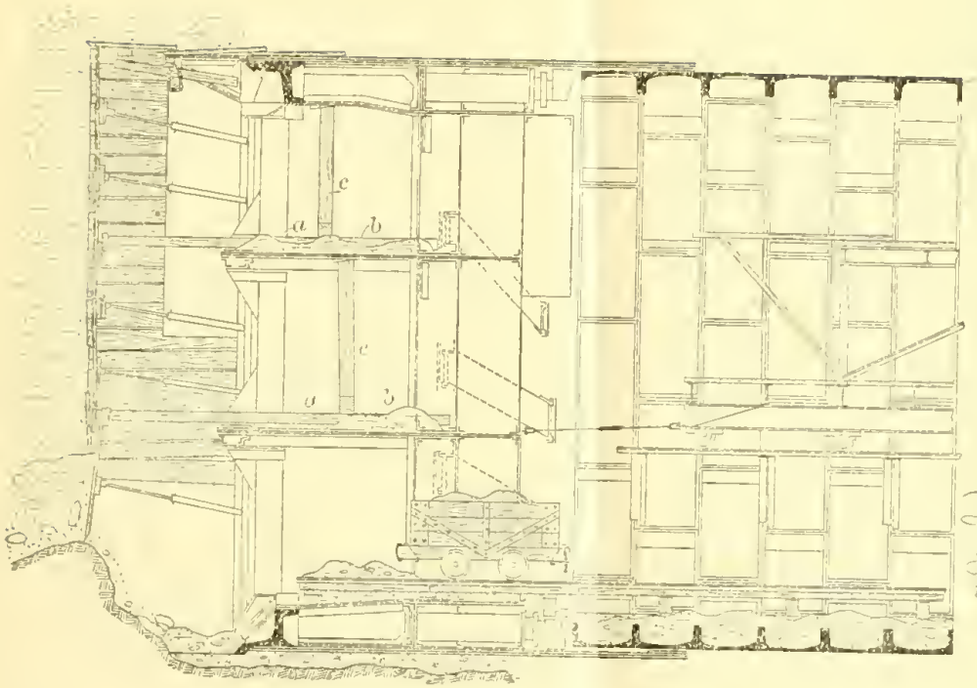
The full-face method was only used where the rock was not considered safe for a heading. A cut was fired at the bottom, together with side holes, in a manner quite similar to that adopted in the first set of holes for a bottom heading. The cradle was then placed, in lengths of either 2.5 or 5 ft., after which the remainder of the face was fired in the same manner as for the bottom-heading method. The closed transverse bulkhead with air-locks, as shown in Fig. 1, Plate LXVI, was placed in the shield in the hope that it would only be necessary to maintain the full air pressure in the working compartments in front of the bulkhead. It was also thought that some form of bulkhead which could be closed quickly and tightly would be necessary to prevent flooding the tunnel in case of blows. While no attempt was ever made to reduce the pressure behind the shield bulkhead, it was obvious from the experience with Tunnels *B* and *D*, while working in the sand between Manhattan and the reef, that the plan was not practicable, and that the closed bulkhead in the bottom was a hindrance instead of a safeguard. As soon as rock was encountered in those tunnels at the west edge of the reef, the contractor cut through the bulkheads and altered them, as shown in Fig. 2, Plate LXVI.

Taking advantage of the experience gained, openings were cut through the bulkheads in Shields *A* and *C*, while they were shut down near the edge of the Manhattan ledge. In erecting the shields at

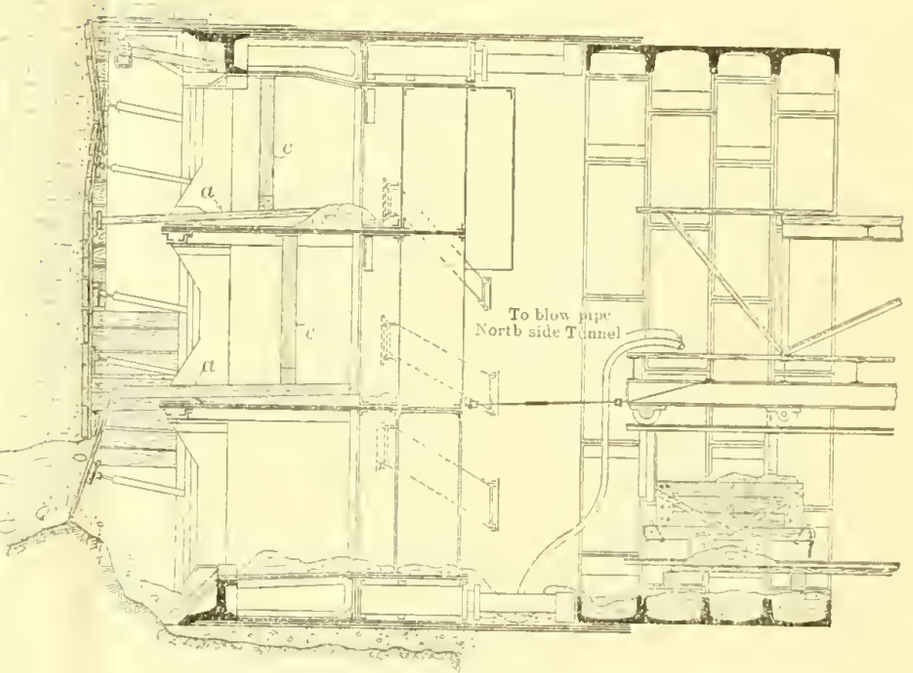
Long Island City in May and June, 1906, openings were also provided. These shields had to pass through about 700 ft. of rock at the start, the greater portion of which was all-rock section. It was at that point that openings were first used extensively and methods were developed, which would not have been possible except where cars could be passed through the shield. The bottom-heading method was first tried, but the working space in front of the shield was cramped, and but few men could be employed in loading the cars. To give more room, the heading was gradually widened. The enlargement at the top, when made from the shield, blocked all work at the face of the heading while the former operation was in progress. To reduce the delays, the heading was raised, thus reducing the quantity of rock left in the top, and the bottom was taken out as a bench. To avoid blocking the tracks when firing the top, a heavy timber platform was built out from the floors of the middle working compartments. Most of the muck from the top was caught on the platform and dropped into cars below. This method of working is shown by Fig. 2, Plate LXVII. The platforms were not entirely satisfactory, and, later, the drills in the heading were turned upward and a top bench was also drilled and fired, as shown by Fig. 3, Plate LXVII. There was then so little excavation left in the top that the muck was allowed to fall on the tracks and was quickly cleared away. The method just outlined is called the center-heading method, and was the most satisfactory plan devised for full-rock sections.

Excavation in Part Rock and Part Earth.—This was probably the most difficult work encountered, particularly when the rock was covered with boulders and coarse sharp sand which permitted a free escape of air. It was necessary, before removing the rock immediately under the soft ground, to excavate the earth in advance of the shield to a point beyond where the rock was to be disturbed, and to support, in some way, the roof, sides, and face of the opening thus made. The hoods were designed mainly for the purpose of supporting the roof and the sides. With the fixed hood it was necessary either to excavate for the distance of the desired shove in front of it or else to force the hood into the undisturbed material. To avoid this difficulty, the sliding hoods were tried as an experiment.

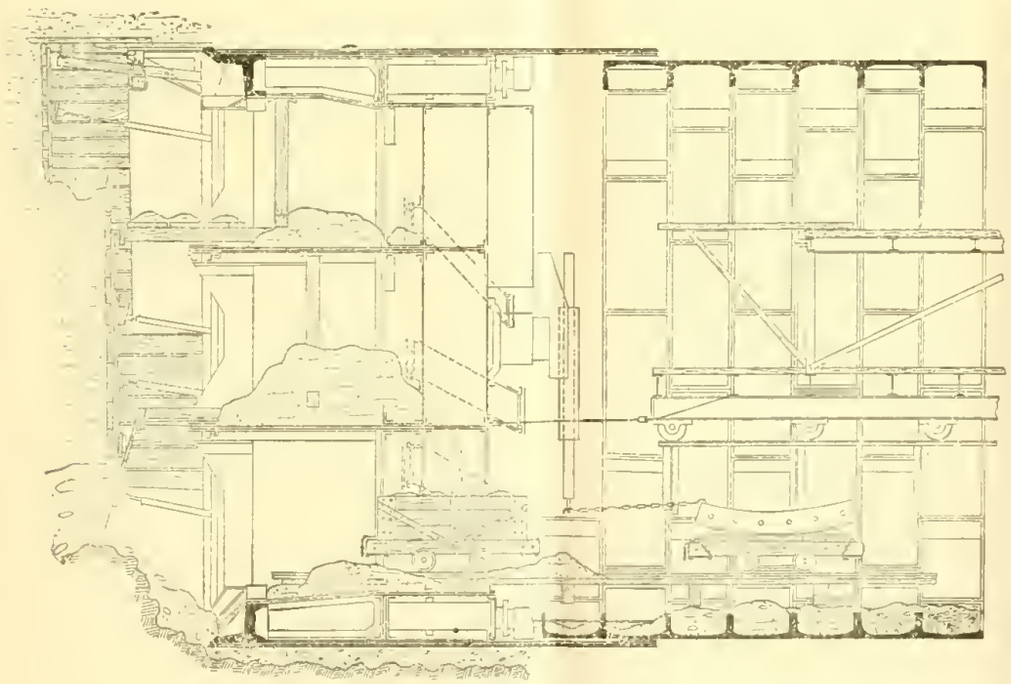
In using the sliding hood, which will be described in detail in Mr. Japp's paper, the segments commencing at the top were forced



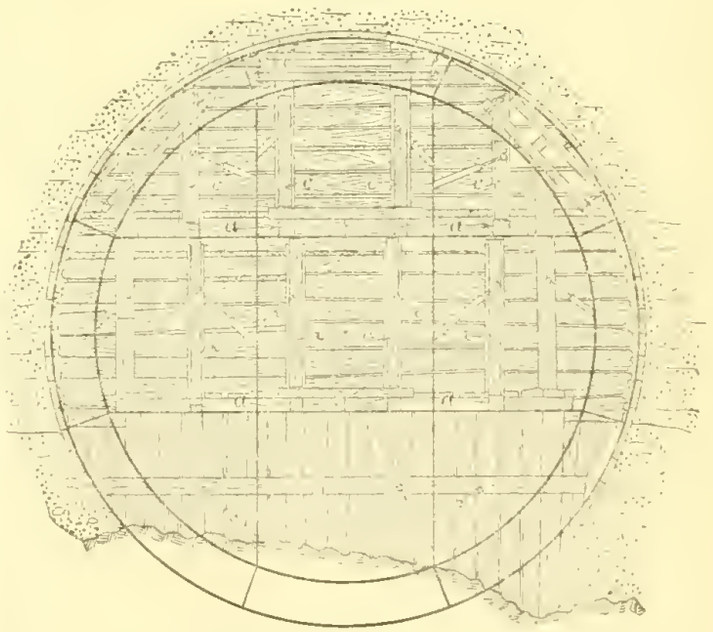
READY FOR SHOVE
FIG. 1.



AFTER SHOVE
FIG. 2.



PREPARING FOR 2D SHOVE. BOTTOM PLATES ERECTED.
FIG. 3.



ELEVATION SHOWING BREASTING
FIG. 4.

forward by the screw rod, one at a time, as far as possible into the undisturbed material. Just enough material was then removed from underneath and in front of the section to free it, and it was again forced forward. These operations were repeated until the section had been extended far enough for a shove. As soon as two or three sections had been pushed forward in this way, the face near the advance end of the sliding hood was protected by a breast board set on edge and braced from the face. Gradually, all the segments were worked forward, and, at the same time, the whole soft ground face was sheeted with timber. At times polings were placed over the extended segments in order to make room for a second shove, as shown on Plate LXVIII. When the shield was advanced the nuts on the screw rods were loosened and the sections of the hoods were telescoped on to the shield. The idea was ingenious, but proved impracticable, because of the unequal relative movements of the top and bottom of the shield in shoving, bringing transverse strains on the hood sections.

With the fixed hood, poling boards were used to support the roof and sides, and the face was supported in the manner described for the sliding hoods. The polings were usually maple or oak planks, 2 in. thick, about 8 in. wide, and 6½ ft. long. In advancing the face, the top board of the old breast was first removed, then the material was carefully worked out for the length of the poling. The latter was then placed, with the rear end resting over the hood and the forward end forced as far as possible into the undisturbed material. When two or three polings had been placed, a breast board was set. After several polings were in position, their forward ends were supported by some form a cantilever attached to the hood. Plate LXIX shows one kind of supports. In this way all the soft material was excavated down to the rock surface, and the roof, sides, and face were sheeted with timber. In shoving, the polings in the roof and sides were lost. It was found that the breast could usually be advanced 5 ft. with safety. The fixed hood made it possible to set the face about 7 or 8 ft. in front of the cutting edge without increasing the length of the polings. This distance was ample for two shoves, and was generally adopted, although a great many faces were set for one shove only.

Fixed hoods were substituted for those of the sliding type, originally placed on Shields *B* and *D* at Manhattan, at about the time the latter encountered the rock at the reef.

In placing the polings and breasting, all voids behind them were filled as far as possible with marsh hay or bags of sawdust or clay. To prevent loss of air in open material, the joints between the boards were plastered with clay especially prepared for the purpose in a pug mill. The sliding extensions to the floors of the working compartments were often used, in the early part of the work, to support the timber face or loose rock, as shown in Fig. 1, Plate LXVIII. At such times the front of the extensions was held tightly against the planking by the pressure of the floor jacks. While shoving, the pressure on the floor jacks was gradually released, allowing the floors to slide back into the shield and still afford support to the face. The extensions also afforded convenient working platforms. They were subject to severe bending strains while the shield was being shoved, however, and the cast-iron rams were frequently broken or jammed. The extensions did not last beyond the edge of the ledge at Manhattan, nor more than about half through the rock work at Long Island City. The fixed extensions originally placed on Shields *A* and *C* at Manhattan were not substantial enough, and lasted only a few days.

Wherever the rock face was sufficiently sound and high, a bottom heading was driven some 20 or 30 ft. in advance of the shield. The heading was driven and the cradle placed independently of the face of the soft ground above, and in the manner described for all-rock sections. The remainder of the rock face was removed by firing top and side rounds into the bottom heading after the soft ground had been excavated. Great care had to be taken in firing in order not to disturb the timber work or break the rock away from under the breast boards. If either occurred, a serious run was likely to follow. The bottom-heading method is shown by Figs. 1, 2, and 3, Plate LXVIII, and the breasting and poling by Fig. 2, Plate LXX.

In the early part of the work, where a bottom heading was impracticable, the soft ground was first excavated as described above, and the rock was drilled by machines mounted on tripods, and fired as a bench. By this plan no drilling could be done until the soft ground was removed. This is called the rock-bench method.

Later the rock-cut method was devised. Drills were set up on columns in the bottom compartments of the shield, and the face was drilled while work was in progress on the soft ground above. The drilling was done either for a horizontal or vertical cut and side and

FIG. 1.—SMALL SHAFT SUNK TO ROCK.

FIG. 2.—BREASTING AND POLING IN FRONT OF SHIELD.

FIG. 3.—SHUTTERS ON FRONT OF SHIELD.

FIG. 4.—HYDRAULIC ERECTOR PLACING SEGMENT.

top rounds. The drillers were protected while at work by platforms of timber built out from the floors of the compartments above. This plan, while probably not quite as economical of explosives, saved nearly all the delay due to drilling the bench.

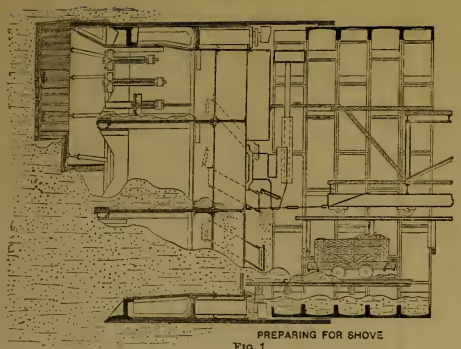
All-Earth Section.—As described by Messrs. Hay and Fitzmaurice, in a paper on the Blackwall Tunnel,* the contractor had used, with marked success, shutters in the face of the shield for excavating in loose open material. He naturally adopted the method for the East River work. When the shields in Tunnels *B* and *D*, at Manhattan, the first to be driven through soft ground, reached a point under the actual bulkhead line, work was partly suspended and shutters were put in place in the face of the top and center compartments. The shutters in the center compartments in Shield *D* are shown in Fig. 3, Plate LXX, while the method of work with the shutters is shown by Figs. 4, 5, 6, and 7, Plate LXVIII. Fig. 4 on that plate shows the shield ready for a shove. As the pressure was applied to the shield jacks, men loosened the nuts on the screws holding the ends of the shutters, and allowed the latter to slide back into the working compartments. At the end of the shove, the shutters were in the position shown in Fig. 5, Plate LXVIII. In preparing for a new shove, the slides in the shutters were opened, and the material in front was raked into the shield. At the same time, the shutters were gradually worked forward. The two upper shutters in a compartment were generally advanced from 12 to 15 in., after which the muck could be shoveled out over the bottom shutters, as shown on Fig. 6, Plate LXVIII, and Fig. 3, Plate LXX. No shutters were placed in the bottom compartments, and as the air pressure was not generally high enough to keep the face dry at the bottom, these compartments were pretty well filled with the soft, wet quicksand. Just before shoving, this material was excavated to a point where it ran in faster than it could be taken out. Much of the excavation in the bottom compartment was done by the blow-pipe. During the shove the material from the bottom compartment often ran back through the open door in the transverse bulkhead, as shown by Fig. 5, Plate LXVIII.

In the Blackwall Tunnel the material was reported to have been loose enough to keep in close contact with the shutters at all times. In the East River Tunnels this was not the case. The sand at the top

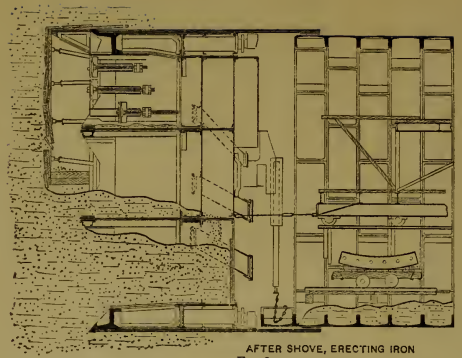
* *Minutes of Proceedings*, Inst. C. E., Vol. CXXX, p. 50.

was dry and would often stand with a vertical face for some hours. In advancing the shutters, it was difficult to bring them into close contact with the face at the end of the operation. The soft material at the bottom was constantly running into the lower compartment and undermining the stiff dry material at the top. The latter gradually broke away, and, at times, the actual face was some feet in advance of the shutters. Under those circumstances, the air escaped freely through the unprotected sand face. The joints of the shutters were plastered with clay, but this did not keep the air from passing out through the lower compartments. This condition facilitated the formation of blows, which were of constant occurrence where shutters were used in the sand. In Tunnels *B* and *D*, at Manhattan, the shutters were used in the above manner clear across to the reef. In Tunnel *C*, which was considerably behind Tunnels *B* and *D*, the shutters, although placed, were never used against the face, and the excavation was carried on by poling the top and breasting the face. The change resulted in much better progress and fewer blows. The excavation through the soft material in Tunnel *C* had just been completed when Tunnel *A* was started, and the gangs of workmen were exchanged.

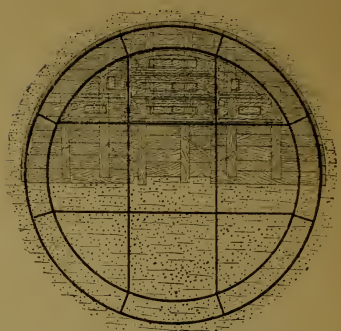
The work in soft ground in Tunnel *A* thus gained the benefit of the experience in Tunnel *C*. Shutters were placed only in the top compartments in this tunnel, and, as in Tunnel *C*, were never used in contact with the face. The method of work is shown by Figs. 1, 2, and 3, Plate LXXI. The result was still more rapid progress in Tunnel *A*, and although the loss of air was fully as great in this tunnel as in the other three, there was only one blow which caused any considerable loss of pressure. In Tunnels *A* and *C* the diaphragms in the rear of the center compartments of the lower tiers of working chambers were removed before the shields entered the soft ground. The change was not of as much advantage in soft ground as in rock, but it facilitated the removal of the soft wet sand in the bottom. In Tunnel *A*, after encountering gravel, a belt conveyor was suspended from the traveling stage with one end projecting through the opening into the working compartment. The use of the conveyor made it possible to continue mucking at the face while the bottom plates of the iron lining were being put in place, and resulted in a material increase in the rate of progress.



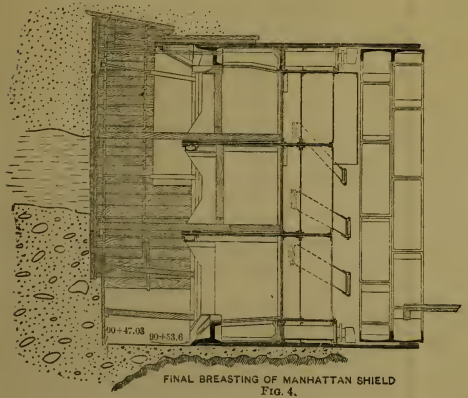
PREPARING FOR SHOVE
FIG. 1.



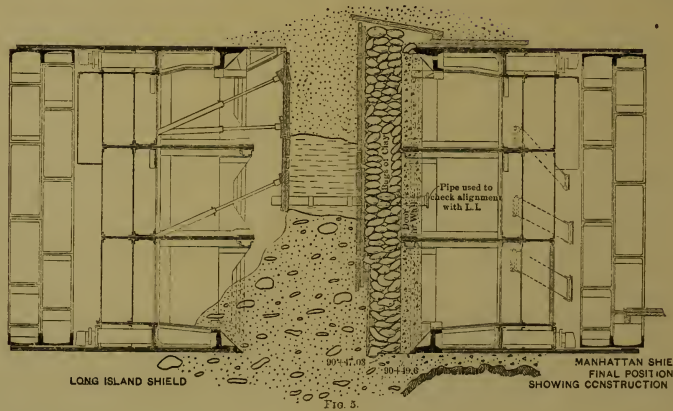
AFTER SHOVE, ERECTING IRON
FIG. 2.



SECTION:- SHUTTERS AND BREASTING
FIG. 3.



FINAL BREASTING OF MANHATTAN SHIELD
FIG. 4.



LONG ISLAND SHIELD

MANHATTAN SHIELD
FINAL POSITION
SHOWING CONSTRUCTION OF BULKHEAD

FIG. 5.

The shutters were not placed on the Long Island shields at all. Just before the shields passed into all soft ground, a fixed hood was attached to each.

The method of working in soft ground from Long Island City is illustrated by Plate LXXII. The full lines at the face of the shield show the position of the earth before a shove of the shield, and the dotted lines show the same after the shove. The face was mined out to the front of the hood and breasted down to a little below the floor of the top pockets of the shield. In the middle pocket the earth was allowed to take its natural slope back on the floor. Toward the rear of the bottom pockets it was held by stop-planks. The air pressure was always about equal to the hydrostatic head at the middle of the shield, so that the face in the upper and middle pockets was dry. In the lower pockets it was wet, and flowed under the pressure of shoving the shield. By this method 4 195 lin. ft. of tunnel was excavated by the four Long Island shields in 120 days, from November 1st, 1907, to March 1st, 1908. This was an average of 8.74 ft. per day per shield.

The rate of progress, the nature of the materials, and the methods adopted are shown in Table 2.

Preparations for Junction of Shields.—As previously mentioned, the Manhattan shields were stopped at the edge of the reef. Before making the final shove of those shields, special polings were placed with unusual care. The excavation was bell-shaped to receive the Long Island shields. The arrangement of the polings is shown by Figs. 4 and 5, Plate LXXI. After the shields were shoved into final position, as shown at the right in Fig. 5, the rear end of the polings rested over the cutting edge and allowed room for the removal of the hood. After the latter had been accomplished, the temporary bulkheads of concrete and clay bags were built as a precaution against blows when the shields were close together. An 8-in. pipe was then driven forward through the bulkhead for distances varying from 30 to 100 ft., in order to check the alignment and grade between the two workings before the shields were actually shoved together. The errors in the surveys were negligible, but here, as elsewhere, the shields were not exactly in the desired position, and it took careful handling to bring the cutting edges together. The Long Island shields were driven to meet those from Manhattan.

TABLE 2.—(*Continued.*)

LINE D, LONG ISLAND.

Material.	Method.	STATION: From	STATION: To	DATE: From	DATE: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
Rock	Bottom heading	68 + 50.6	69 + 77	June 2, '06	Oct. 24, '06	144	126.4	0.87	
Earth and rock.	Bottom heading	69 + 77	71 + 22	Oct. 24, '06	Jan. 13, '07	81	145	1.79	
All rock	Bottom heading	71 + 22	72 + 00	Jan. 13, '07	Mar. 3, '07	49	78	1.59	
All rock	Center heading	72 + 00	75 + 73	Mar. 3, '07	July 10, '07	129	373	2.89	
Earth and rock.	Going out of rock	75 + 73	77 + 63	July 10, '07	Sept. 25, '07	77	190	2.47	
All earth	Soft ground	77 + 63	90 + 38.6	Sept. 25, '07	Mar. 7, '08	164	1 275.6	7.78	

LINE A, MANHATTAN.

Rock	Top heading	108 + 43	107 + 74	July 20, '05	Aug. 3, '05	14	69	1.21	Excavation in normal air, and before advance of shield.
	Top lift of bench	108 + 43	107 + 74	Aug. 8, '05	Aug. 23, '05	15 (57)			
	Bottom lift of bench	108 + 43	107 + 74	Aug. 30, '05	Sept. 27, '05	28			
Rock	Bottom heading	107 + 74	107 + 21	Sept. 27, '05	Oct. 23, '05	26 (55)	53	0.96	Bottom heading timbered to avoid the possibility of a break.
	Bottom heading	107 + 74	107 + 21	Nov. 30, '05	Dec. 29, '05	29			
Mixed	Bottom heading	107 + 21	106 + 99	Oct. 26, '06	Nov. 20, '06	25	22	0.88	Bottom heading timbered.
Mixed	Rock bench	106 + 99	106 + 34	Nov. 20, '06	Jan. 13, '07	54	65	1.20	
Earth	Poling and breasting	106 + 34	99 + 11	Jan. 13, '07	Apr. 17, '07	94	723	7.69	
Mixed	Rock cut	99 + 11	93 + 96	Apr. 17, '07	Oct. 24, '07	190	515	2.71	
Rock	Bottom heading	93 + 96	93 + 58	Oct. 24, '07	Nov. 14, '07	21	38	1.81	
Rock	Center heading	93 + 58	92 + 42	Nov. 14, '07	Dec. 27, '07	46	116	2.52	
Rock	Bottom heading	92 + 42	91 + 05	Dec. 27, '07	Feb. 24, '08	59	137	2.32	
Mixed	Rock cut	91 + 05	90 + 57	Feb. 24, '08	Mar. 20, '08	25	48	1.92	

TABLE 2.—Rate of Progress, Nature of Materials, and Methods Adopted in Construction of East River Tunnels.

Line A, Long Island.

Material.	Method.	Station: From	Station: To	Date: From	Date: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
All rock	Bottom heading	69 + 39.9	69 + 79	Aug. 2, '06	Sept. 25, '06	54	39.1	0.724	
All rock	Center heading	69 + 79	70 + 64	Sept. 25, '06	Nov. 21, '06	57	85	1.49	
Earth and rock.	Center heading	70 + 64	71 + 34	Nov. 21, '06	Dec. 30, '06	39	70	1.79	
Earth and rock.	Bottom heading	71 + 34	71 + 89	Dec. 30, '06	Feb. 13, '07	45	55	1.22	
All rock	Bottom heading	71 + 89	72 + 11	Feb. 13, '07	Feb. 21, '07	8	22	2.75	
Earth and rock.	Center heading	72 + 11	72 + 67	Feb. 21, '07	Mar. 19, '07	26	56	2.15	
All rock	Center heading	72 + 67	76 + 54	Mar. 19, '07	Sept. 6, '07	171	387	2.26	
Earth and rock.	Going out of rock	76 + 54	77 + 24	Sept. 6, '07	Oct. 4, '07	28	70	2.50	
All earth	Soft ground	77 + 24	90 + 57.3	Oct. 4, '07	Mar. 26, '08	174	1 333.3	7.66	

Line B, Long Island.

Material.	Method.	Station: From	Station: To	Date: From	Date: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
All rock	Bottom heading	69 + 29.6	70 + 46	Oct. 16, '06	Nov. 20, '06	35	116.4	3.33	
Earth and rock.	Bottom heading	70 + 46	71 + 95	Nov. 20, '06	Feb. 23, '07	95	149	1.57	
All rock	Bottom heading	71 + 95	72 + 25	Feb. 23, '07	Mar. 6, '07	11	30	2.73	
Earth and rock.	Center heading	72 + 25	72 + 60	Mar. 6, '07	Mar. 24, '07	18	35	1.94	
All rock	Going out of rock	72 + 60	76 + 57	Mar. 24, '07	Aug. 7, '07	136	397	2.92	
Earth and rock.	Soft ground	76 + 57	77 + 30	Aug. 7, '07	Sept. 5, '07	29	73	2.52	
All earth	Soft ground	77 + 30	90 + 49.6	Sept. 5, '07	Mar. 19, '08	196	1 319.6	6.73	

Line C, Long Island.

Material.	Method.	Station: From	Station: To	Date: From	Date: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
All rock	Bottom heading	68 + 61.9	69 + 93	June 11, '06	Oct. 16, '06	127	131.1	1.03	
Earth and rock.	Bottom heading	69 + 93	71 + 65	Oct. 16, '06	Feb. 7, '07	114	172	1.51	
All rock	Bottom heading	71 + 65	71 + 91	Feb. 7, '07	Feb. 13, '07	6	26	4.33	
All rock	Center heading	71 + 91	75 + 81	Feb. 13, '07	July 20, '07	157	390	2.48	
Earth and rock.	Going out of rock	75 + 81	76 + 56	July 20, '07	Aug. 25, '07	36	75	2.08	
All earth	Soft ground	76 + 56	90 + 44.4	Aug. 25, '07	Mar. 17, '08	205	1 388.4	6.77	

TABLE 2.—(*Continued.*)

LINE C, MANHATTAN.—(*Continued.*)

Material.	Method.	STATION: From	STATION: To	DATE: From	DATE: To	No. of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
Mixed.....	Rock cut.....	106 + 17	105 + 85	Apr. 2, '06	Apr. 20, '06	18	32	1.78	Shut down on account of air shortage.
Mixed.....	Rock cut.....	105 + 85	105 + 55	July 27, '06	Aug. 26, '06	30	30	1.00	Shut down April 20th to July 27th, 1906.
Earth.....	Breasting and poling.....	105 + 55	99 + 40	Aug. 26, '06	Jan. 2, '07	127	615	4.84	
Mixed.....	Rock cut.....	99 + 40	98 + 70	Jan. 2, '07	Feb. 6, '07	35	70	2.00	
Rock.....	Full face.....	98 + 70	98 + 60	Feb. 6, '07	Feb. 12, '07	6	10	1.66	
Mixed.....	Bottom heading...	98 + 60	98 + 39	Feb. 12, '07	Mar. 6, '07	22	21	0.95	
Rock.....	Bottom heading...	98 + 39	98 + 17	Mar. 6, '07	Mar. 15, '07	9	22	2.44	
Mixed.....	Rock cut.....	98 + 17	95 + 68	Mar. 15, '07	July 30, '07	110	249	2.26	Heading advanced to 97 + 82.
Rock.....	Middle heading....	95 + 68	94 + 61	July 30, '07	Aug. 21, '07	49	107	2.18	" " " 94 + 35.
Mixed.....	Rock cut.....	94 + 61	93 + 56	Aug. 21, '07	Oct. 3, '07	43	106	2.46	
Rock.....	Middle heading....	93 + 56	92 + 73	Oct. 3, '07	Nov. 11, '07	39	83	2.13	
Mixed.....	Rock cut.....	92 + 73	90 + 55	Nov. 11, '07	Feb. 13, '08	94	218	2.32	Shut down until Line D shields met.
Mixed.....	Rock cut.....	90 + 55	90 + 44.4	Feb. 25, '08	Mar. 3, '08	6	11	1.83	

LINE D, MANHATTAN.

Material.	Method.	STATION: From	STATION: To	DATE: From	DATE: To	No. of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
Rock.....	Top heading.....	107 + 70.49	107 + 16	Dec. 9, '04	Jan. 31, '05	123	90	0.73	In normal air.
	Removing bench..	107 + 70.49	107 + 35	Jan. 1, '05	Jan. 27, '05				
	Bottom heading...	107 + 35	106 + 80	Jan. 30, '05	Feb. 10, '05				
	Trimming.....	107 + 70	106 + 80	Mar. 29, '05	Apr. 12, '05				
	Trimming.....	107 + 70	106 + 80	Aug. 31, '05	Sept. 19, '05				
Rock.....	Bottom heading...	106 + 80	106 + 67	Oct. 5, '05	Nov. 8, '05	34	13	0.40	Bottom heading timbered.
Mixed.....	Bottom heading...	106 + 67	106 + 29	Nov. 8, '05	Dec. 23, '05	45	38	0.84	
Mixed.....	Sliding hood and breasting. Rock bench.....	106 + 29	105 + 70	Dec. 23, '05	Jan. 24, '06	32	59	1.84	
Earth.....	Poling and breasting.....	105 + 70	104 + 61	Jan. 24, '06	Feb. 27, '06	31	109	3.41	
Earth.....	Poling, breasting and shutters....	104 + 61	103 + 90	Mar. 2, '06	Mar. 31, '06	29	71	2.45	Three days' delay to set shutters in top. Shut down 20 days to permit consolidation of the river bed and to repair broken plates.

TABLE 2.—(*Continued.*)

LINE B, MANHATTAN.

Material.	Method.	Station: From	Station: To	Date: From	Date: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
Rock	Top heading	108 + 35	107 + 87	July 6, '05	July 27, '05	21	48	0.94	Excavation done in normal air and before advance of shield.
	Top lift of bench	108 + 35	107 + 87	Aug. 3, '05	Aug. 14, '05	11			
	Bottom lift of bench	108 + 35	108 + 15	Aug. 26, '05	Aug. 30, '05	4			
	Bottom lift of bench	108 + 15	107 + 87	Sept. 11, '05	Sept. 26, '05	15			
Rock	Bottom heading	107 + 87	107 + 00	Oct. 23, '05	Jan. 17, '06	86	87	1.01	
Mixed	Bottom heading	107 + 00	106 + 64	Jan. 17, '06	Feb. 12, '06	26	36	1.38	
Mixed	Rock bench	106 + 64	106 + 31	Feb. 12, '06	Mar. 1, '06	17	33	1.94	
Earth	Poling and breasting	106 + 31	105 + 58	Mar. 1, '06	Apr. 3, '06	33	73	2.21	
Earth	Shutters in contact with face	105 + 58	99 + 19	Apr. 9, '06	Nov. 1, '06	206	639	3.10	
Mixed	Rock bench	99 + 19	98 + 44	Nov. 1, '06	Dec. 29, '06	58	75	1.30	
Mixed	Bottom heading	98 + 44	97 + 76	Dec. 29, '06	Feb. 12, '07	45	68	1.51	
Mixed	Rock cut	97 + 66	93 + 84	Feb. 12, '07	Aug. 6, '07	175	392	2.24	
Rock	Full face	93 + 84	93 + 21	Aug. 6, '07	Sept. 2, '07	27	63	2.33	
Rock	Center heading	93 + 21	92 + 30	Sept. 2, '07	Oct. 12, '07	40	91	2.28	
Rock	Bottom heading	92 + 30	90 + 99	Oct. 12, '07	Dec. 6, '07	55	131	2.38	
Mixed	Rock cut	90 + 99	90 + 49.6	Dec. 6, '07	Jan. 3, '08	28	49.4	1.76	

LINE C, MANHATTAN.

Material.	Method.	Station: From	Station: To	Date: From	Date: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
Rock	Top heading	107 + 79.03	107 + 69	Dec. 20, '04	Dec. 27, '04	7	54	0.77	Stopped to brace portal. No work done from March 19th to October 11th, 1905, except a little trimming in September. All work up to this date done in normal air. Heading advanced to 106 + 70 and bulkheaded.
	Top heading	107 + 69	107 + 23	Jan. 1, '05	Jan. 15, '05	14			
	Excavating bench	107 + 79	107 + 23	Jan. 21, '05	Feb. 28, '05	38			
	Bottom heading	107 + 23	106 + 72	Mar. 1, '05	Mar. 11, '05	10			
	Bottom heading	107 + 23	107 + 15	Oct. 12, '05	Oct. 27, '05	15			
Rock	Bottom heading	107 + 15	106 + 62	Nov. 6, '05	Dec 2, '05	26	53	2.04	
Mixed	Bottom heading	106 + 62	106 + 55	Dec. 2, '05	Dec. 23, '05	21	7	0.33	Heading advanced to 106 + 40. Shut down in order that Line D might have a lead.
Mixed	Bottom heading	106 + 55	106 + 17	Feb. 12, '06	Mar. 22, '06	38	38	1.00	Shut down on account of air shortage.

TABLE 2.—(*Continued.*)

LINE D, MANHATTAN.—(*Continued.*)

Material.	Method.	STATION: From	STATION: To	DATE: From	DATE: To	Number of days.	Linear feet.	Rate of progress, in feet per day.	Remarks.
Earth	Shutters	103 + 90	99 + 41	Apr. 20, '06	Sept 3, '06	136	449	3.40	Four days of 136, delay account of flood.
Mixed	Bottom bench	99 + 41	99 + 17	Sept. 3, '06	Sept. 23, '06	20	24	1.20	
Mixed	Bottom heading	99 + 17	98 + 50	Oct. 2, '06	Nov. 24, '06	53	67	1.27	Thirteen days' shut-down to put on hood.
Rock	Bottom heading	98 + 50	97 + 72	Nov. 24, '06	Jan. 16, '07	53	78	1.47	
Mixed	Bottom heading	97 + 72	97 + 27	Jan. 16, '07	Feb. 10, '07	25	45	1.10	
Mixed	Rock cut	97 + 27	95 + 72	Feb. 10, '07	Apr. 23, '07	72	155	2.15	
Rock	Middle heading	95 + 72	95 + 57	Apr. 23, '07	May 11, '07	18	15	0.83	
Rock	Middle heading	95 + 57	94 + 65	May 23, '07	June 17, '07	25	92	3.68	Twelve days' delay to repair cutting edge.
Mixed	Middle heading	94 + 65	94 + 41	June 17, '07	June 25, '07	8	24	3.00	
Mixed	Rock cut	94 + 41	94 + 03	June 25, '07	July 13, '07	18	38	2.11	
Rock	Middle heading	94 + 03	92 + 64	July 13, '07	Sept. 12, '07	61	139	2.28	
Mixed	Middle heading	92 + 64	92 + 54	Sept. 12, '07	Sept. 20, '07	8	10	1.25	
Rock	Middle heading	92 + 54	92 + 50	Sept. 20, '07	Sept. 21, '07	1	4	4.00	
Mixed	Rock cut	92 + 50	90 + 38.66	Sept. 21, '07	Jan. 8, '08	109	211.34	1.94	

Openings were made between the headings as follows:

Tunnel *D*, February 20th, 1908;
Tunnel *B*, March 3d, 1908;
Tunnel *C*, March 5th, 1908;
Tunnel *A*, March 18th, 1908.

It was necessary to cut away the projecting floors of the working compartments before the cutting edges could be shoved together.

Contractor's Organization.—Tunnel operations were carried on continuously for thirteen days out of fourteen, regular work being shut down for repairs on alternate Sundays. When the required pressure was more than 32 lb., four gangs of laborers were employed, each gang working two shifts of 3 hours each, with an intermission of 3 hours between the shifts. When the pressure was less than 32 lb., three gangs were employed, each gang covering 8 hours, but with an intermission of about ½ hour in low pressure for lunch.

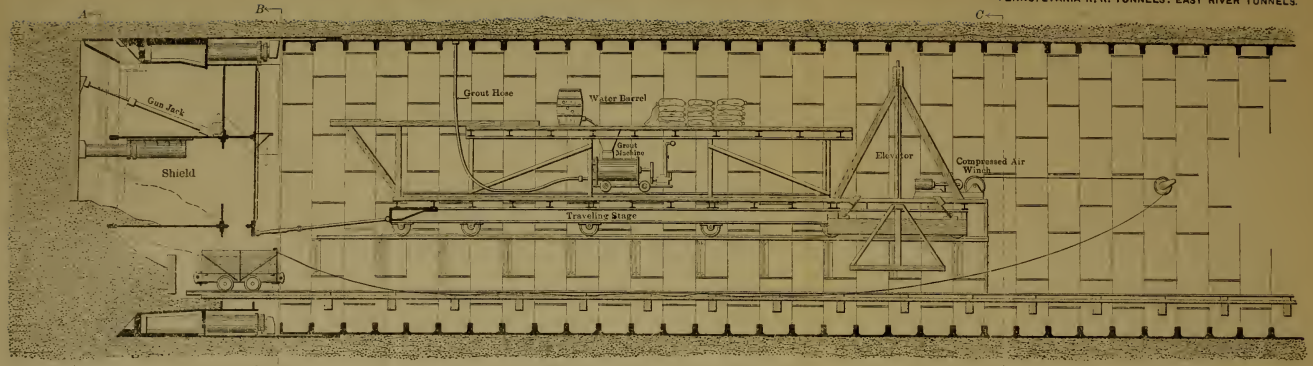
Air Pressures Required.—During the greater portion of the work in soft ground, pressure was maintained which would about balance the hydrostatic head at the axis of the tunnel. This required a pressure varying from 30 to 34 lb. per sq. in. above that of the atmosphere. In Tunnels *B* and *D*, at Manhattan, during the work in soft ground, pressures as high as 37 lb. were maintained for considerable periods of time; in the firm material near the reef 28 lb. was often sufficient. While removing the broken plates, the pressure was raised for a short time to 42 lb., and was maintained between 37½ and 40 lb. for a little more than one month.

Air Supply.—For regular operation the contractor furnished four compressors on each side of the river, each having a rated capacity of 5 000 cu. ft. of free air per minute delivered at 50 lb. above normal, when running at the rate of 100 rev. per min. An additional compressor of the same capacity was supplied on each side of the river, in compliance with the requirement for 25% excess capacity; the additional compressors had also high-pressure air cylinders which could be connected at will, and in which the pressure could be increased to 150 lb., and the air used to supply rock drills, grouting machines, etc. The entire combination on each side of the river, therefore, was rated at 25 000 cu. ft. of free air per minute, or a mean of 6 250 cu. ft. per heading. Its safe working capacity was not far from 20 000 cu. ft. per min.

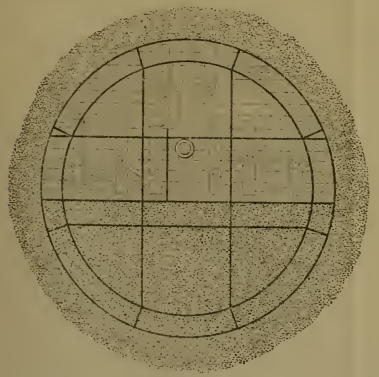
The shields broke through rock surface in Tunnels *B*, *C*, and *D*, at Manhattan, in November and December, 1905. The consumption of air in the four tunnels soon exceeded 15 000 cu. ft. for 24 hours, and in Tunnel *D*, on several occasions, it exceeded 7 000 cu. ft. for a like period. Blows had become frequent, and it was evident that the air plant was inadequate for driving four tunnels at once in the open material east of the Manhattan rock. Work in Tunnel *A*, therefore, was not resumed, after the suspension on December 29th, for about ten months, and Tunnel *C* was also closed down for more than four months of the time between December, 1905, and July, 1906. During this period the capacity of the plant was increased from the rated 25 000 cu. ft. of free air per minute, to 35 000. In Tunnel *D* the material had gradually become firmer, with more clay and less escape of air, as the Blackwell's Island Reef was approached, and, at the end of the period, the rock surface was within 3 ft. of the top of the shield; in Tunnel *B*, the rock of the reef was still a little below the shield, but the overlying material contained a large proportion of clay and held air very well. Tunnel *C* was still in open material, but, with two lines safe and with the increased air plant, it was deemed best to resume work in Tunnel *A*, which was done on October 23d, 1906. Thenceforward work was continuous in all headings until the meeting points with the Long Island shields were reached.

This period, January to October, 1906, inclusive, was the most strenuous of the entire work, particularly the first six months. With one and, at times, two tunnels closed down, the consumption of air in the headings from Manhattan was an average of more than 20 000 cu. ft. per min. for periods of from 30 to 60 days; it was often more than 25 000 cu. ft. for 24 hours, with a maximum of nearly 29 000 cu. ft., and doubtless this was exceeded considerably for shorter periods. On several occasions the quantity supplied to a single tunnel averaged more than 15 000 cu. ft. per min. for 24 hours. The greatest averages for 24 hours were obtained later in Tunnel *A*, after the resumption of work there, and exceeded 19 000 cu. ft., but the conditions in the headings of the other lines were then so favorable that the work was carried on continuously in all.

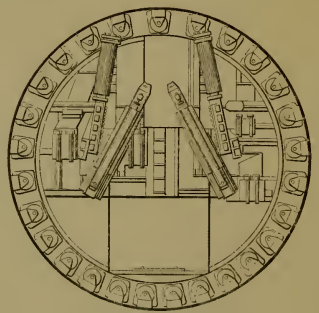
The deficiency in the original plant at Manhattan was so marked, and the need of driving all headings from Long Island simultaneously so clear, that it was decided to increase the rated capacity of the Long



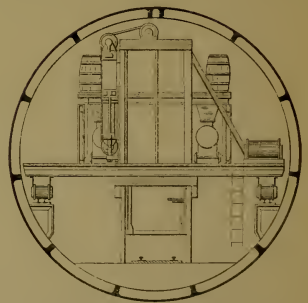
SECTIONAL ELEVATION LOOKING NORTH
FIG.1



SECTION *A-A*
FIG.2



SECTION *B-B*
SHOWING BACK VIEW OF SHIELD
FIG.3



SECTION *C-C*
SHOWING BACK VIEW OF TRAVELING STAGE
FIG.4

Island compressor plant to 45 400 cu. ft. of free air per minute, which was 10 400 cu. ft. greater than the capacity of the Manhattan plant after the latter had been augmented.

The earth encountered on emerging from rock, when driving westward from Long Island, was far more compact and less permeable to air than on the Manhattan side, but for a distance of from 400 to 600 ft. immediately east of the reef, it was a clean open sand, and, while the shields were passing through this, the quantity of air supplied to the four headings seldom fell below 20 000 cu. ft. per min.; it was usually more than 25 000 cu. ft., with a recorded maximum of 33 400 cu. ft. Although this was greater than ever used on the Manhattan side, it was more uniformly distributed among the several headings, and in none equalled the maximum observed on the Manhattan side, the largest having been 12 700 cu. ft. per min. for 24 hours; it must be remembered, however, that at one time only two tunnels were in progress in the bad material in the tunnels from Manhattan.

From the foregoing experience, it would seem that the plant finally furnished at Long Island, having a rated capacity of 45 400 cu. ft. of free air per minute, would have been a reasonable compliance with the original actual needs on the Manhattan side and *vice versa;* the plant finally developed on the Manhattan side, having a rated capacity of 35 000 cu. ft. of free air per minute, would have sufficed for the Long Island side.

The total quantity of free air compressed for the supply of the working chambers of the tunnels and the Long Island caissons was 34 109 000 000 cu. ft., and, in addition, 10 615 000 000 cu. ft. were compressed to between 80 and 125 lb. for power purposes, of which at least 80% was exhausted in the compressed-air working chambers. The total supply of free air to each heading while under pressure, therefore, averaged about 3 550 cu. ft. per min.

The quantity of air escaping during a sudden blow-out is apparently much smaller than might be supposed. Investigation of a number of cases, showing large pressure losses combined with a long stretch of tunnel supplying a relatively large reservoir of air, disclosed that a maximum loss of about 220 000 cu. ft. of free air occurred in 10 min. This averages only a little more than 19 000 cu. ft. per min., the maximum recorded supply to one tunnel for a period of 24 hours. Of this

quantity, however, probably from 30 to 40% escaped in the first 45 seconds, while the remainder was a more or less steady loss up to the time when the supply could be increased sufficiently to maintain the lowered pressure. Very few blows showed losses approaching this in quantity, but the inherent inaccuracy of the observations make the foregoing figures only roughly approximate.

Special Difficulties.

The most serious difficulties of the work came near the start. In Tunnel *D* blows and falls of sand from the face were frequent after soft ground was met in the top. About six weeks after entering the full sand face, and before the shutters had been installed, the shield showed a decided tendency to settle, carrying the tunnel lining down with it and resulting in a number of badly broken plates in the bottom of the rings. Notwithstanding the use of extremely high vertical leads,* the sand was so soft that the settlement of the shield continued for about fifteen rings, the maximum being nearly 9 in. below grade. The hydrostatic head at mid-height of the tunnel was 32½ lb., and the raising of the air pressure to 37 lb., as was done at this time, was attended with grave danger of serious blows, on account of the recent disturbance of the natural cover by the pulling and re-driving of piles in the reconstruction of the Long Island ferry slips directly above. It dried the face materially, however, and the shield began to rise again, and had practically regained the grade when the anticipated blow-outs occurred, culminating with the entrance of rip-rap from the river bed into the shield and the flooding of the tunnel with 4 ft. of sand and water at the forward end. The escape of air was very great, and, as a pressure of more than 28 lb. could not be maintained, the face was bulkheaded and the tunnel was shut down for three weeks in order to permit the river bed to consolidate.

This was the most serious difficulty encountered on any part of the work, and, coming at the very start, was exceedingly discouraging. During the shut-down the broken plates were reinforced temporarily with steel ribs and reinforced concrete (Fig. 1, Plate LXXIII) which, on completion of the work, were replaced by cast-steel segments, as described elsewhere. Practically, no further movement of iron took place, and the loss of grade caused by the settlement of the shield,

* The lead of the shield is the angular divergence of its axis from the axis of the tunnel and, in this tunnel, was measured as the offset in 23 ft. It was called + when the shield was pointed upward from grade, and — when pointed downward.

PLATE LXXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVIII, No. 1159.
BRACE, MASON, AND WOODARD ON
PENNSYLVANIA R. R. TUNNELS: EAST RIVER TUNNELS.

FIG. 1.—TEMPORARY REINFORCEMENT OF BROKEN PLATES AND REMOVAL OF A PLATE IN SECTIONS.

FIG. 2.—HEAVY CAST-STEEL PATCH ATTACHED TO BENT SEGMENT OF CUTTING EDGE.

FIG. 3.—INFLOW OF SOFT CLAY THROUGH SHIELD.

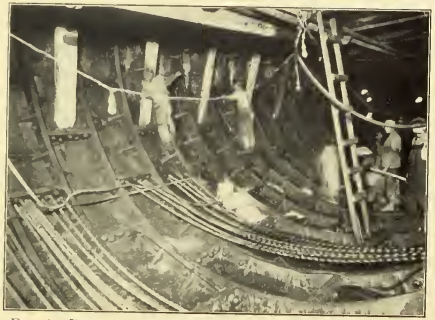


FIG. 4.—REINFORCEMENT OF BROKEN PLATE WITH LONG BOLT AND TWISTED STEEL RODS.

which was by far the largest that ever occurred in this work, was not sufficient to require a change in the designed grade or alignment of the track. Work was resumed with the shutters in use at the face as an aid to excavation. The features of extreme seriousness did not recur, but for two months the escape of air continued to be extremely large, an average of 15 000 cu. ft. per min. being required on many days during this period.

In Tunnel *B*, after passing out from under the bulkhead line, in April, 1906, the loss of air became very great, and blow-outs were of almost daily occurrence until the end of June. At the time of the blows the pressure in the tunnel would drop from 2 to 8 lb., and it generally took some hours to raise the pressure to what it was before the blow. During that time regular operations were interrupted. In the latter part of June a permit was obtained allowing the clay blanket to be increased in thickness up to a depth of water of 27 ft. at mean low tide. The additional blanket was deposited during the latter part of June and early in July, and almost entirely stopped the blows.

By the end of the month the natural clay, previously described, formed the greater portion of the face, and, from that time forward, played an important part in reducing the quantity of air required. During April and the early part of May the work was under the ferry racks of the Long Island Railroad. The blanket had to be placed by dumping the clay from wheel-barrows through holes in the decking.

In Tunnel *A* a bottom heading had been driven 23 ft. in advance of the face at the time work was stopped at the end of 1905. During the ten months of inactivity the seams in the rock above opened. The rock surface was only from 2 to 4 ft. below the top of the cutting edge for a distance of about 60 ft. Over the rock there were large boulders embedded in sharp sand. It was an exceedingly difficult operation to remove the boulders and place the polings without starting a run. The open seams over the bottom heading also frequently caused trouble, as there were numerous slides of rock from the face which broke up the breasting and allowed the soft material from above to run into the shield. There were two runs of from 50 to 75 cu. yd. and many smaller ones.

Guiding the Shields.

Little difficulty was experienced at any time in driving the shield close to the desired line, but it was much harder to keep it on grade. In rock section, where the cradle could be set far enough in advance

to become hard before the shield was shoved over it, there was no trouble whatever. Where the cradle could be placed only a very short time before it had to take the weight of the shield, the case was quite different. The shield had a tendency to settle at the cutting edge, and when once pointed downward it was extremely difficult to change its direction. It was generally accomplished by embedding railroad rails or heavy oak plank in the cradle on solid foundation. This often had to be repeated several times before it was successful. In soft ground it was much easier to change the direction of the shield, but, owing to the varying nature of the material, it was sometimes impossible to determine in advance how the shield should be pointed. It was found by experience at Manhattan that the iron lining remained in the best position in relation to grade when the underside of the bottom of the shield at the rear end was driven on grade of the bottom of the iron, but if the rate of progress was slow, it was better to drive the shield a little higher.

In the headings from Long Island, which, as a rule, were in soft ground, the cutting edges of the shields were kept from 4 to 8 in. higher, with respect to the grade line, than the rails. The shields would then usually move parallel to the grade line, though this was modified considerably by the way the mucking was done and by the stiffness of the ground at the bottom of the shield.

On the average, the shields were shoved by from ten to twelve of the bottom jacks, with a pressure of about 4 000 lb. per sq. in. The jacks had 9-in. plungers, which made the average total force required to shove the shield 2 800 000 lb. In the soft ground, where shutters were used, all of the twenty-seven jacks were frequently used, and on several occasions the pressure exceeded 6 000 lb. per sq. in. With a unit pressure of 6 000 lb. per sq. in., the total pressure on the shield with all twenty-seven jacks in operation was 5 154 tons.

Injuries to Shields.

There were only two instances of damage to the essential structural features of the shields. The most serious was in Tunnel *D* where the cutting edge at the bottom of the shield was forced up a slightly sloping ledge of rock. A bow was formed in the steel casting which was markedly increased with the next few shoves. Work was suspended, and a heavy cast-steel patch, filling out the bow, was attached to the bent segments, as shown in Fig. 2, Plate LXXIII. No further trouble

was experienced with the deformed portion. The other instance was in Tunnel *B*, from Long Island, where a somewhat similar but less serious accident occurred and was treated in a like manner.

Bulkheads.—At Manhattan, bulkheads had to be built near the shafts before the tunnels could be put under pressure. After 500 ft. of tunnel had been built on each line, the second bulkheads were constructed. The air pressure between the first and second bulkheads was then reduced to between 15 and 20 lb. When the shields had been advanced for 1 500 ft., the third set of bulkheads was built. Nearly all the broken plates which were removed were located between the first and third bulkheads at Manhattan. Before undertaking this operation, the doors of the locks in the No. 3 bulkheads were reversed to take pressure from the west. By this means it was possible to carry on the work of dismantling the shields under comparatively low pressure simultaneously with the removal of the broken plates.

At Long Island City the roofs of the caissons served the purpose of the No. 1 bulkheads. Two other sets of bulkheads were erected, the first about 500 ft. and the second about 1 500 ft. from the shafts.

Settlement at Surface of Ground.

The driving of such portions of the river tunnels, with earth top, as were under the land section, caused a settlement at the surface varying usually from 3 to 6 in. The three-story brick building at No. 412 East 34th Street required extensive repairs. This building stood over the section of part earth and part rock excavation where the tunnels broke out from the Manhattan ledge and where there were a number of runs of sand into the shield. In fact, the voids made by those runs eventually worked up to the surface and caused the pavement of the alley between the buildings to drop 4 or 5 ft. over a considerable area. The tunnels also passed directly under the ferry bridges and racks of the Long Island Railroad at East 34th Street. Tunnels *B* and *D* were constantly blowing at the time, and, where progress was slow, caused so much settlement that one of the racks had to be rebuilt. Tunnel *A*, on the other hand, where progress was rapid, caused practically no settlement in the racks.

Clay Blanket.

As previously mentioned, clay was dumped over the tunnels in varying depths at different times. A material was required which would

pack into a compact mass and would not readily erode under the influence of the tidal currents of the river and the escape of the great volumes of air which often kept the water in the vicinity of the shields in violent motion. Suitable clay could not be found in the immediate vicinity of the work. Materials from Shooter's Island and from Haverstraw were tried for the purpose. The Government authorities did not approve of the former, and the greater portion of that used came from the latter point. Although a number of different permits governing the work were granted, there were three important ones. The first permit allowed a blanket which roughly followed the profile of the tunnels, with an average thickness of 10 ft. on the Manhattan side and somewhat less on the Long Island City side. The second general permit allowed the blanket to be built up to a plane 27 ft. below low water. This proved effective in checking the tendency to blow, but allowed considerable loss of air. Finally, dumping was allowed over limited and marked areas up to a plane of 20 ft. below low water. Wherever advantage was taken of this last authority, the excessive loss of air was almost entirely stopped. After all the shields had been well advanced out into the river, the blanket behind them was dredged up, and the clay used over again in advance of the shield.

Soundings were taken daily over the shields, and, if marked erosion was found, clay was dumped into the hole. Whenever a serious blow occurred, a scowload of clay was dumped over it as soon as possible and without waiting to make soundings. For the latter purposes a considerable quantity of clay was placed in storage in the Pidgeon Street slip at Long Island City, and one or two bottom-dump scows were kept filled ready for emergencies. Mr. Robert Chalmers, who had charge of the soundings for the contractor, states that "the depressions in the blanket caused by erosion due to the escape of air were, as a rule, roughly circular in plan and of a curved section somewhat flat in the center." Satisfactory soundings were never obtained in the center of a violent blow, but the following instance illustrates in a measure what occurred. Over Tunnel *B*, at Station 102+80, there was normally 36 ft. of water, 7 ft. of clay blanket, and 20 ft. of natural cover. Air was escaping at the rate of about 10 000 cu. ft. per min., and small blows were occurring once or twice daily. On June 22d, soundings showed 54 ft. of water. A depth of 18 ft. of the river bottom had been eroded in about two days. On the next day there were taken out of the

shield boulders which had almost certainly been deposited on the natural river bed. Clay from the blanket also came into the shields on a number of occasions during or after blows. The most notable occasion was in September, 1907, when the top of the shield in Tunnel *D* was emerging from the east side of Blackwell's Island Reef. The sand in the top was very coarse and loose, and allowed the air to escape very freely. The fall of a piece of loose rock from under the breast precipitated a run of sand which was followed by clay from the blanket, which, in this locality, was largely the softer redredged material. Mucking out the shield was in progress when the soft clay started flowing again and forced its way back into the tunnel for a distance of 20 ft., as shown in Fig. 3, Plate LXXIII. Ten days of careful and arduous work were required to regain control of the face and complete the shove, on account of the heavy pressure of the plastic clay.

The clay blanket was of the utmost importance to the work throughout, and it is difficult to see how the tunnels could have been driven through the soft material on the Manhattan side without it.

The new material used in the blanket amounted to 283 412 cu. yd., of which 117 846 cu. yd. were removed from over the completed tunnels and redeposited in the blanket in advance of the shields. A total of 88 059 cu. yd. of clay was dumped over blows. The total cost of placing and removing the blanket was $304 056.

Iron Lining.

The standard cast-iron tunnel lining was of the usual tube type, 23 ft. in outside diameter. The rings were 30 in. wide, and were composed of eleven segments and a key. The webs of the segments were $1\frac{1}{2}$ in. thick in the central portion, increasing to $2\frac{3}{8}$ in. at the roots of the flanges, which were 11 in. deep, $2\frac{1}{4}$ in. thick at the root, and $1\frac{1}{2}$ in. at the edge, and were machined on all contact faces. Recesses were cast in the edge of the flanges, forming a groove, when the lining was in place, $1\frac{1}{2}$ in. deep and about $\frac{3}{8}$ in. wide, to receive the caulking. The bolt holes were cored in the flanges, and the bosses facing the holes were not machined. The customary grout hole was tapped in the center of each plate for a standard $1\frac{1}{4}$-in. pipe. In this work, experience indicated that the standard pipe thread was too fine, and that the taper was objectionable. Each segment weighed, approximately, 2 020 lb., and the key weighed 520 lb., the total weight being 9 102 lb. per

lin. ft. of tunnel. Fig. 1 shows the details of the standard heavy lining.

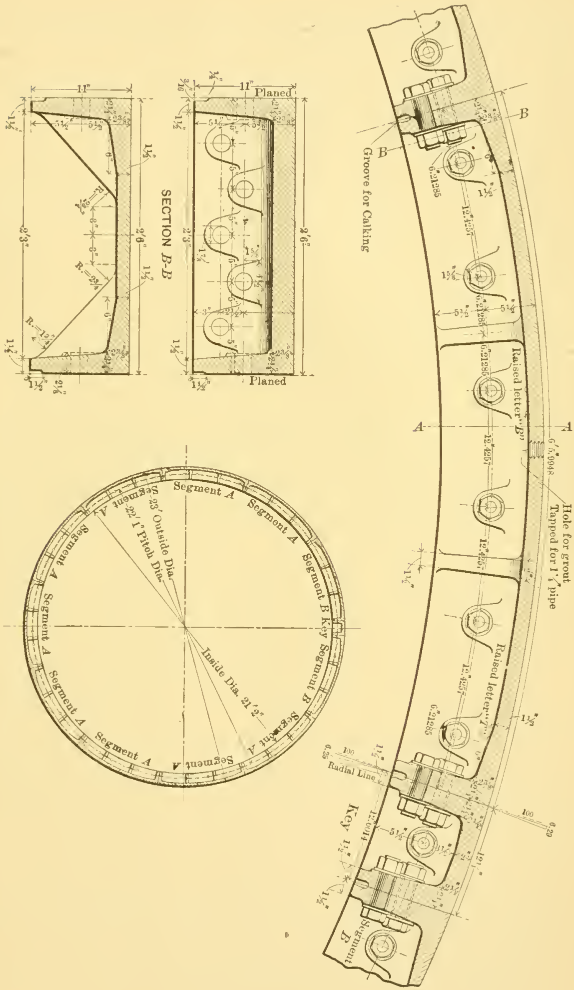
In addition to the standard cast-iron lining, cast-steel rings of the same dimensions were provided for use in a short stretch of the tunnel, when passing from a rock to a soft ground foundation, where it was anticipated that unequal settlement and consequent distortion and increase in stress might occur, but, aside from the small regular drop of the lining as it passed out of the tail of the shield, no such settlement was observed.

Two classes of lighter iron, one with 1-in. web and 8-in. flanges and the other with $1\frac{1}{4}$-in. web and 9-in. flanges—the former weighing 5 166 lb. per lin. ft. of tunnel and the latter, 6 776 lb.—were provided for use in the land sections between East Avenue and the Long Island City shafts. Two weights of extra heavy segments for use at the bottom of the rings were also furnished. The so-called *XX* plates had webs and flanges $\frac{1}{4}$ in. thicker than the standard segment and the *YY* plates were similarly $\frac{1}{2}$ in. heavier. The conditions under which they were used will be referred to later. All the castings were of the same general type as shown by Fig. 1.

Rings tapering $\frac{3}{4}$ in. and $1\frac{1}{2}$ in. in width were used for changes in alignment and grade, the former being used approximately at every fourth ring on the 1° 30′ curves. The $1\frac{1}{2}$-in. tapers were largely used for changes in grade where it was desired to free the iron from binding on the tail of the shield. Still wider tapers would have been advantageous for quick results in this respect.

No lug was cast on the segments for attachment to the erector, but in its place the gadget shown on Fig. 4, Plate LXX, was inserted in one of the pairs of bolt holes near the center of the plate, and was held in position by the running nut at one end.

In the beginning it was expected that the natural shape of the rings would not show more than 1 in. of shortening of the vertical diameter; this was slightly exceeded, however, the average distortion throughout the tunnels being $1\frac{7}{16}$ in. The erectors were attached to the shield and in such a position that they were in the plane of the center of the ring to be erected when the shove was made without lead and just far enough to permit placing the segments. If the shield were shoved too far, a rare occurrence, the erection was inconvenienced. In driving with high vertical leads, which occurred more frequently, the dis-



CAST-IRON RING FOR TUBE TUNNEL.

Fig. 1.

advantage of placing the erector on the shield was more apparent. Under such conditions the plane of the erector's motion was acutely inclined to the plane of the ring, and, after placing the lower portion of the ring, it was usually necessary to shove the shield a few inches farther in order to place the upper plates. The practical effect of this action is referred to later.

At first the erection of the iron in the river tunnels interfered somewhat with the mucking operations, but the length of time required to complete the latter was ample for the completion of the former; and the starting of a shove was seldom postponed by reason of the non-completion of a ring. After the removal of the bottom of the diaphragms, permitting the muck cars to be run into the shield and beyond, the two operations were carried on simultaneously without serious interference. The installation of the belt conveyor for handling the soft ground spoil in Tunnel *A* was of special benefit in this respect.

Preparatory to the final bolt tightening of each ring as erected, a 15-ton draw-jack, consisting of a small pulling-jack inserted in a light eye-bar chain, was placed on the horizontal diameter, and frequently the erectors were also used to boost the crown of the iron, the object being to erect the ring truly circular. Before shoving, a $1\frac{1}{4}$-in. turnbuckle was also placed on the horizontal diameter in order to prevent the spreading of the iron, previous to filling the void outside with grout. The approach of the supports for the upper floor of the trailing platform necessitated the removal of these turnbuckles from all but the three leading rings, but if the iron showed a tendency to continue distortion, they were re-inserted after the passage of the trailing platform and remained until the arch of the concrete lining was placed.

The cost of handling and erecting the iron varied greatly at different times, averaging, for the river tunnels, \$3.32 per ton for the directly chargeable labor of handling and erecting, to which must be added \$7.54 for "top charges." The cost of repairing broken plates is included in this figure.

Broken Plates.—During the construction of the river section of the tunnels, a number of segments were found to have been broken while shoving the shield. The breaks, which with few exceptions were confined to the three or four bottom plates, almost invariably occurred on the advanced face of the ring, and rarely extended beyond the bottom

of the flange. A careful study of the breaks and of the shoving records disclosed several distinct types of fracture and three principal known causes of breakage by the shield.

In the first case, the accidental intrusion of foreign material between the jack head and the iron caused the jack to take its bearings on the flange above its normal position opposite the web of the ring, and resulted usually in the breaking out of a piece of the flange or in several radiating cracks with or without a depression of the flange. These breaks were very characteristic, and the cause was readily recognizable, even though the intruding substance was not actually observed.

In the second case, the working of a hard piece of metal, such as a small tool, into the annular space between the iron and the tail of the shield, where it was caught on the bead and dragged along as the shield advanced, was the known cause of a number of broken segments. Such breaks had no particular characteristic, but were usually close above the line of travel of the lost tool or metal. Their cause was determined by the finding of a heavy score on the underside of the segment or the discovery of the tool wedged in the tail of the shield or lying under the broken plate when it was removed. It is probable that a number of breaks ascribed to unknown causes should be placed in this class.

The third cause includes the largest number of breaks, and, while difficult to define closely, is the most interesting. Broadly speaking, the breaks resulted from the movements of the shield in relation to the position of the tunnel lining. While shoving through soft ground, it was frequently difficult to apply sufficient power to the lower jacks to complete the full shove of 30 in. on the desired alignment. The shield, therefore, was driven upward at the beginning of the shove, and, as the sand packed in front of the shield and more power was required, it was furnished by applying the upper jacks. The top of the shield was slowly pushed over, and, at the close of the shove, the desired position had been obtained; but the shield had been given a rocking motion with a decided lifting of the tail toward the close of the shove. A similar lifting of the tail occurred when, with high vertical leads, the top of the shield was pushed over in order to place the upper plates of the ring. Again, when the shield was driven above grade and it was desired to descend, the passage of the shield over the summit pro-

duced a like effect. In all these movements, with the space between the tail of the shield and the iron packed tight with pugging, the upward thrust of the shield tended to flatten the iron in the bottom and occasional broken plates were the result. The free use of the taper rings, placed so as to relieve the binding of the lining on the tail of the shield, forces the tunnel to follow the variations in the grade of the shield, but reduces greatly the injuries to the rings from this action.

In Tunnel *D*, where very high vertical leads were required through the soft sand, combined with a marked tendency of the shield to settle, the shield was badly cramped on the iron and dragged along it at the top. The bearing of the iron on its soft foundation tended to thrust up the bottom in this case also, as shown by the opening of the bottom cross-joints when the bolts were slackened to relieve the strain during a shove. The anticipated cracks in the crown plates, which have been more frequently observed in other tunnels, did not occur here, and were not found elsewhere except in one place in Tunnel *B* where they were traced to a similar action of the shield. The cracks resulting from the movements of the shield, as briefly described above, in this third case were not confined to any particular type, but occurred more frequently at the extreme end of the circumferential flange than at any other point.

The number of broken plates occurring in the river tunnels was 319, or 0.42% of the total number erected. Of these, 52 were found and removed, either before or immediately after a shove, by far the greater number being broken in handling before or during erection. The remaining 267 are considered below.

Repair of Broken Plates.—On the completion of a shove, the tail of the shield lacked about 5 in. of covering the full width of the last ring, and the removal of a plate broken during the shove, therefore, would have exposed the ground at the tail of the shield. With a firm material in the bottom, this introduced no particular difficulties, and, under such conditions, a broken plate was usually removed at once. In the sand, however, and especially on the Manhattan side where it was quick and flowing, the removal of a plate was attended with some danger, and such plates were usually left to be removed on the completion of the tunnel. Many of these had been reinforced by the use of *XX*, *YY*, and steel segments placed adjacent to the break in the following rings.

After the meeting of the shields, the postponed replacement of the

broken segments was taken up. The pressure was raised sufficiently to dry thoroughly the sand outside the segments, which were drilled and broken out usually in quarters as shown on Fig. 1, Plate LXXIII. A steel segment was then inserted in the ring and drawn into place by turnbuckles. The application of the draw-jack, with a pull of about 30 tons to each end successively, brought the plate to a firm bearing on the radial joints at the ends.

Where the broken plate was isolated and was reinforced by steel or extra heavy segments in the adjacent ring, the crack, if slight, was simply caulked to insure water-tightness. If, however, the crack was opened or extended to the web of the plate, the cross-flanges were tied together by a 1½-in. by 7-ft. bolt, inserted through the bolt holes nearest the broken flange. The long bolt acted in the nature of a bow string, and was provided at its ends with two nuts set on opposite sides of the cross-joints to replace the standard bolts removed for its insertion. Fig. 4, Plate LXXIII shows one of these bolts in place. In addition, all broken plates remaining in the tunnel were reinforced with 1-in. twisted-steel rods in the concrete lining, also shown in Fig. 4, Plate LXXIII.

Special Construction at River Shield Junctions.—Dismantling the shields was started as soon as they came to rest in their final position with the cutting edges together. The plans contemplated their entire removal, with the exception of the cylindrical skins and cast-steel cutting edges. Inside the former the standard tunnel lining was erected to within 4 ft. of the heels of the cutting edges. Spanning the latter, and forming the continuous metal tunnel lining, the special construction shown by Fig. 2 was built. This consisted of a 1¼ in. rolled-steel ring, 7 ft. long, erected inside the cutting edges, with an annular clearance of 1 in., and two special cast-iron rings shaped to connect the rolled-steel ring with the normal lining. One flange of the special cast-iron rings was of the standard type, the other was returned 9 in. in the form of a ring, the inside diameter of which was the same as the outside diameter of the rolled-steel ring to which it was bolted.

The space between the standard and special construction was of varying width at the various shields, and was filled with a closure ring cast to the lengths determined in the field. Fig. 2 shows the completed construction.

Hook-bolts, screwed through threaded holes and buried in 1 to 1 Portland cement grout ejected through similar holes, reinforced the rolled-steel ring against external water pressure. In two of the tunnels the concrete lining was carried completely through the junction, and covered the whole construction, while in the remaining two tunnels it was omitted at the rolled-steel ring, leaving the latter exposed and set back about 3 in. from the face of the concrete.

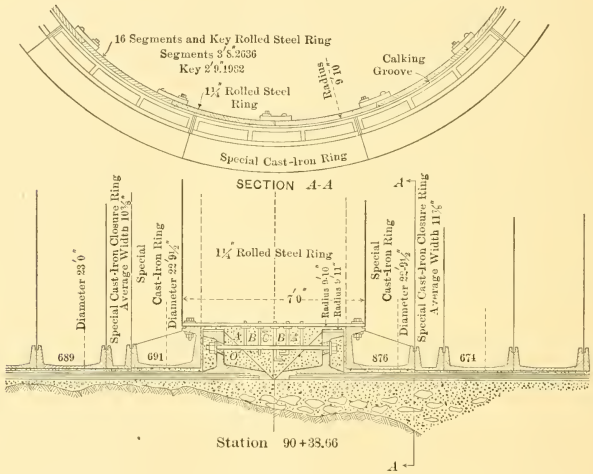


FIG. 2.

GROUTING.

Except as previously noted, the voids outside of the tunnel lining were filled with grout ejected through the grout holes in each segment. The possibility was always present that Portland cement, if used for grout in the shield-driven tunnels, would flow forward around the shield and set hard, "freezing" the shield to the rock or the iron lining, or at least forming excrescences upon it, which would render its control difficult. With this in mind, the contractors proposed to substitute an English Blue Lias lime as a grouting material. Grout of fresh English lime containing a moderate quantity of water set very rapidly in air to the consistency of chalk. Its hydraulic properties, however,

were feeble, and in the presence of an excess of water it remained at the consistency of soft mud. It was not suitable, therefore, as a supporting material for the tunnel.

An American lime, made in imitation of the Lias lime, but having greater hydraulic properties, was tried, but proved unsatisfactory. Two brands of natural cement were also tried and rejected, but a modified quick-setting natural cement, manufactured especially for this work, was eventually made satisfactory, and by far the largest part of the river-tunnel grouting was done with this material mixed 1 to 1 by volume. East of the Long Island shafts the work which was built without shields was grouted principally with Portland cement and sand mixed 1 to 1 by volume.

In the river tunnels large quantities of the English lime were used neat as grout over the top of the tunnel in attempts to stop losses of air through the soft ground. It was not of great efficiency, however, in this respect until the voids outside of the lining had been filled above the crown. Its properties of swelling and quick setting in the dry sand at that point then became of value. The use of dry lime in the face, where the escaping air would carry it into the voids of the sand and choke them, was much more promptly efficacious in checking the loss.

With the exception of the English lime, all grout was mixed 1 to 1 with sand in a Cockburn continuous-stirring machine operated by a 3-cylinder air engine. The grout machine was placed on the lower floor of the trailing platform shown on Plate LXXII, while the materials were placed on the upper platform, and, together with the water, were fed into the machine through a hole in the upper floor. The sand was bagged in the yard, and the cars on which the materials were sent into the tunnels were lifted by an elevator to the level of the upper floor of the trailing platform before unloading.

Great difficulty was experienced in preventing the waste of the fluid grout ahead of the shield and into the tail through the space between it and the iron lining. In a full soft ground section, the first condition did not usually arise. In the full-rock sections the most efficient method of checking the waste was found to be the construction of dams or bulkheads outside the lining between it and the rock surface. For this purpose, at intervals of about 30 ft., the leading ring and the upper half of the preceding one were disconnected and pulled forward sufficiently to give access to the exterior. A rough dam of rubble, or

bags of mortar or clay, was then constructed outside the iron, and the rings were shoved back and connected up. In sections containing both rock and soft ground, grout dams were built at the cutting edge at intervals, and were carried up as high as circumstances permitted.

The annular space at the tail of the shield was at all times supposed to be packed tight with clay and empty bags, but the pugging was difficult to maintain against the pressure of the grout. For a time, ½-in. segmental steel plates, slipped down between the jackets and the iron, were used to retain the pugging, but their displacement resulted in a number of broken flanges, and their use was abandoned. In their place, 2-in. segmental plates attached to the jack heads were substituted with more satisfactory results. Notwithstanding these devices, the waste of grout at the tail was very great.

The soft ground material on various portions of the work acted very differently. The clay and "bull's liver" did not cave in upon the iron lining for several hours after the shield had passed, sometimes not for a day or more, which permitted the space between it and the iron to be grouted. The fine gray or beach sand and the quicksand closed in almost at once. The quicksand has a tendency to fill in under the iron from the sides and in places to leave a cavity at about the horizontal diameter which was not filled from above, as the sand, being dried out by the air, stood up fairly well and did not cave against the iron, except where nearly horizontal at the top.

The total quantity of grout used on the work was equivalent in set volume to 249 647 bbl. of 1 to 1 Portland cement grout, of which 233 647 bbl. were ejected through the iron lining, an average of 14.93 bbl. per lin. ft. The cost of grout ejected outside of the river tunnels was 93 cents per bbl. for labor and $2.77 for "top charges." East of the Long Island shaft the corresponding costs were $0.68 and $1.63, the difference being partly due to the large percentages of work done in the normal air at the latter place.

Caulking and Leakage.

Up to August, 1907, the joints between the segments of the cast-iron lining were caulked with iron filings and sal ammoniac, mixed in the proportion of 400 to 1 by weight. With the air pressure balancing the hydrostatic head near the tunnel axis, it was difficult to make the rust-joint caulking tight below the axis against the opposing water pressure;

this form of caulking was also injured in many places by water dripping from service pipes attached to the tunnel lining. A few trials of lead wire caulked cold gave such satisfactory results that it was adopted as a substitute. Pneumatic hammers were used successfully on the lead caulking, but were only used to a small extent on the rust borings, which were mostly hand caulked. Immediately before placing the concrete lining, all leaks, whether in the rust borings or lead, were repaired with lead, and the remainder of the groove was filled with 1 to 1 Portland cement mortar, leaving the joints absolutely water-tight at that time. The subsequent development of small seepages through the concrete would seem to indicate that the repair work should have been carried on far enough in advance of the concreting to permit the detection of secondary leaks which might develop slowly. The average labor cost chargeable against the caulking was 12 cents per lin. ft., to which should be added 21.8 cents for "top charges."

Unfortunately, it was necessary to place the greater part of the concrete lining in the river tunnels during the summer months when the temperature at the point of work frequently exceeded 85°; and the temperature of the concrete while setting was much higher. This abnormal heat, due to chemical action in the cement, soon passed away, and, with the approach of winter, the contraction of the concrete resulted in transverse cracks. By the middle of the winter these had developed quite uniformly at the ends of each 30-ft. section of concrete arch as placed, and frequently finer cracks showed at about the center of each 30-ft. section.

While the temperature of the concrete was falling, a like change was taking place in the cast-iron lining, with resulting contraction. The lining had been erected in compressed air, the temperature of which averaged about 70° in winter and higher in summer. Compressed air having been taken off in the summer of 1908, the tunnels then acquired the lower temperature of the surrounding earth, slowly falling until mid-winter. The contraction of the concrete, firmly bedded around the flanges of the iron, and showing cracks at fairly uniform intervals, probably localized the small corresponding movements of the iron near the concrete cracks, and resulted in a loosening of the caulking at these points. With the advent of cold weather, damp spots appeared in numerous places on the concrete, and small seepages showed through quite regularly at the temperature cracks, in some cases developing

sufficiently to be called leaks. Only a few, however, were measurable in amount.

Early in January small brass plugs were firmly set on opposite sides of a large number of cracks, and caliper readings and air temperature observations were taken regularly throughout the winter and spring. The widths of the cracks and the amount of leakage at them increased with each drop in temperature and decreased as the temperature rose again, but until spring the width of the cracks did not return to the same point with each return of temperature.

The leakage was similar in all four tunnels, but was largest in amount in Tunnel *D*, where, at the beginning of February, the ordinary flow was about 0.0097 cu. ft. per sec., equivalent to 0.00000347 cu. ft. per sec. per lin. ft. of tunnel. Of this amount 0.0065 cu. ft. per sec. could be accounted for at eight of the cracks showing measurable leakage, leaving 0.0032 cu. ft. per sec. or 0.00000081 cu. ft. per sec. per lin. ft. of tunnel to be accounted for as general seepage distributed over the whole length.

It was not feasible to stop every leak in the tunnel, most of which were indicated simply by damp spots on the concrete; a rather simple method was devised, however, for stopping the leaks at the eight or ten places in each tunnel where water dripped from the arch or flowed down the face of the concrete. The worst leak in any tunnel flowed about 0.0023 cu. ft. per sec. To stop these leaks, rows of 1-in. holes, at about 4-in. centers, were drilled with jap drills through the concrete to the flange of the iron. These rows were from 3 to 18 ft. long, extending 1 ft. or more beyond the limits of the leak. The bottoms of the holes were directly on the caulking groove and the pounding of the drill usually drove the caulking back, so that the leak became dry or nearly so after the holes were drilled. If left alone the leaks would gradually break out again in a few hours or a few days and flow more water than before. They were allowed to do this, however, in only a few cases as experiments. After the holes were drilled, the bottom 4 in. next the flange was filled with soft neat cement mortar. Immediately on top of this was placed two plugs of neat cement about $2\frac{1}{2}$ in. long, which were 5 or 6 hours old and rather hard. Each was tamped in with a round caulking tool of the size of the hole driven with a sledge hammer. On top of this were driven in the same way two more plugs of neat cement of the same size, which were hard set.

These broke up under the blows of the hammer, and caulked the hole tight. When finished, the tamping tool would ring as though it was in solid rock. Great pressure was exerted on the plastic mortar in the bottom of the hole, which resulted in the re-caulking of the joint of the iron. No further measurable leakage developed in the repaired cracks, during a period of four months, and the total leakage has been reduced to about 0.002 cu. ft. per sec. in each tunnel, an average of 0.00000051 cu. ft. per sec. per lin. ft.

Sump and Pump Chambers.

To take care of the drainage of the tunnels, a sump with a pump chamber above it was provided for each pair of tunnels. The sumps were really short tunnels underneath the main ones and extending approximately between the center lines of the latter. They were 10 ft. 9½ in. in outside diameter and 44 ft. long. The water drops directly from the drains in the center lines of the tunnels into the sumps. Above the sumps and between the tunnels, a pump chamber 19 ft. 5 in. long was built. Above the end of the latter, opposite the sump, a cross-passage was constructed between the bench walls of the two tunnels. This passage gives access from either tunnel through an opening in the floor to the pump chamber and through the latter to the sump.

From the preliminary borings it was thought that the sumps were located so that the entire construction would be in rock. This proved to be the case on Tunnels *C* and *D*, but not on Tunnels *A* and *B*. The position of the rock surface in the latter is shown by Fig. 3. After the excavation was completed in Tunnel *B*, January 1st, 1908, the plates were removed from the side of the tunnel at the cross-passage, and a drift was driven through the earth above the rock surface across to the lining of Tunnel *A*. The heading was timbered as shown by Fig. 3. There was practically no loss of air from the drift, but the clay blanket had been removed from over this locality and the situation caused some anxiety. In order to make the heading as secure as possible, the 24-in. I-beams, shown on Fig. 3, were attached to the lining of the two tunnels. The beams formed a support for the permanent concrete roof arch of the passage, which was placed at once. At the same time plates were removed from the bottom in Tunnel *B* over the site of the sump, and a heading was started on the line of the sump

toward Tunnel *A*. As soon as the heading had been driven beyond the center line of the pump chamber, a bottom heading was driven from a break-up westward in the pump chamber and a connection was made with the cross-passage. The iron lining of the pump chamber was next placed, from the cross-passage eastward. The soft ground was excavated directly in advance of the lining, and the ground was supported by polings in much the same manner as described for shield work. On account of bad ground and seams of sand encountered in the rock below the level of the cross-beams, the entire west wall of the pump chamber was placed before enlarging the sump to full size. This was also judicious, in order to support as far as possible the iron lining of the tunnels. The sump was then excavated to full size. The iron lining of the sump and the east wall of the pump chamber were placed as soon as possible. The voids outside the iron lining of the sump and the pump chamber were filled as completely as possible with concrete, and then thoroughly grouted. Finally, the concrete lining was put in place inside of the iron.

As shown by Fig. 3, the excavation of these chambers left a considerable portion of the iron lining of the tunnels temporarily unsupported on the lower inner quarter. To guard against distortion, a system of diagonals and struts was placed as shown.

The floor of the pump chamber was water-proofed with felt and pitch in a manner similar to that described for the caissons at Long Island City. It was not possible to make the felt stick to the vertical walls with soft pitch, which was the only kind that could be used in compressed air, and, therefore, the surfaces were water-proofed by a wall of asphalt brick laid in pitch melting at 60° Fahr. Forms were erected on the neat line, and the space to the rock was filled with concrete making a so-called sand-wall similar to that commonly used for water-proofing with felt and pitch. The bricks were then laid to a height of four or five courses. The joints were filled with pitch instead of mortar. Sheets of tin were then placed against the face of the wall and braced from the concrete forms. As much pitch as possible was then slushed between the brick and the sand-wall, after which the concrete in the main wall was filled up to the top of the water-proofing course. The tin was then withdrawn and the operation repeated. This method was slow and expensive, but gave good results. Ordinary pitch could not be used on account of the fumes, which are

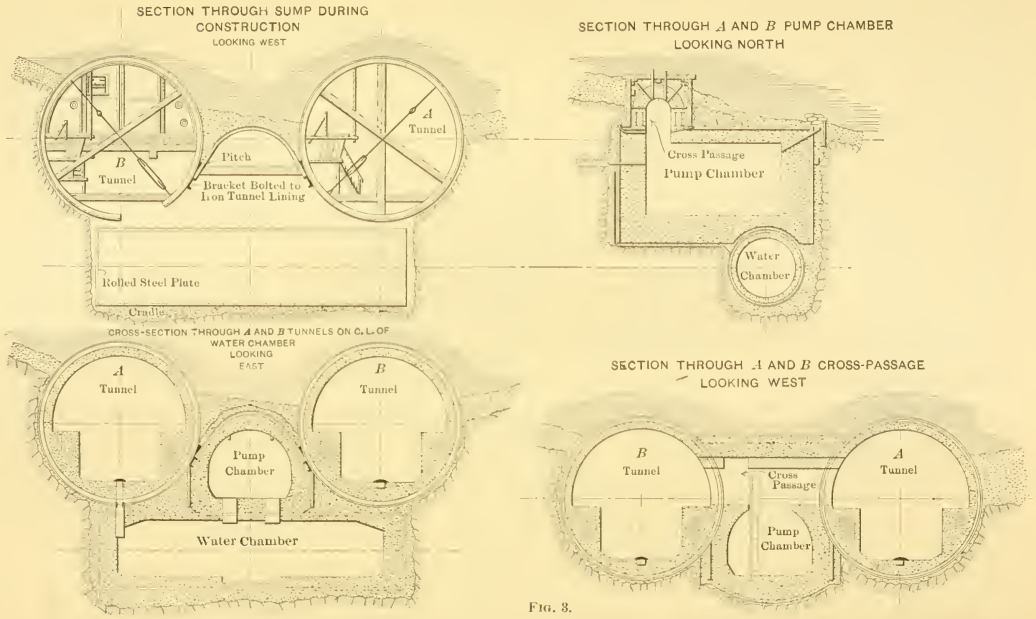

SECTION THROUGH SUMP DURING CONSTRUCTION
LOOKING WEST
A Tunnel
B Tunnel
Pitch
Bracket Bolted to Iron Tunnel Lining
Rolled Steel Plate
Cradle
SECTION THROUGH A AND B PUMP CHAMBER
LOOKING NORTH
Cross Passage
Pump Chamber
Water Chamber
CROSS-SECTION THROUGH A AND B TUNNELS ON C. L. OF WATER CHAMBER
LOOKING EAST
A Tunnel
B Tunnel
Pump Chamber
Water Chamber
SECTION THROUGH A AND B CROSS-PASSAGE
LOOKING WEST
B Tunnel
Cross Passage
A Tunnel
Pump Chamber

FIG. 3.

particularly objectionable in compressed air. The 60° pitch was slightly heated in the open air before using.

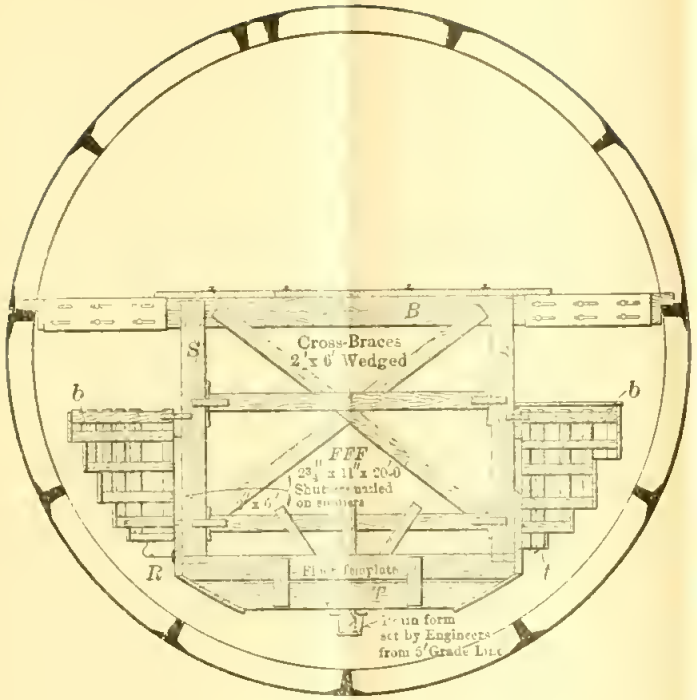
The sump and pump chamber on Tunnels *C* and *D* differed from the one described only in minor details; but, being wholly constructed in rock, presented fewer difficulties and permitted a complete envelope of water-proofing to be placed in the top.

Concrete Lining.

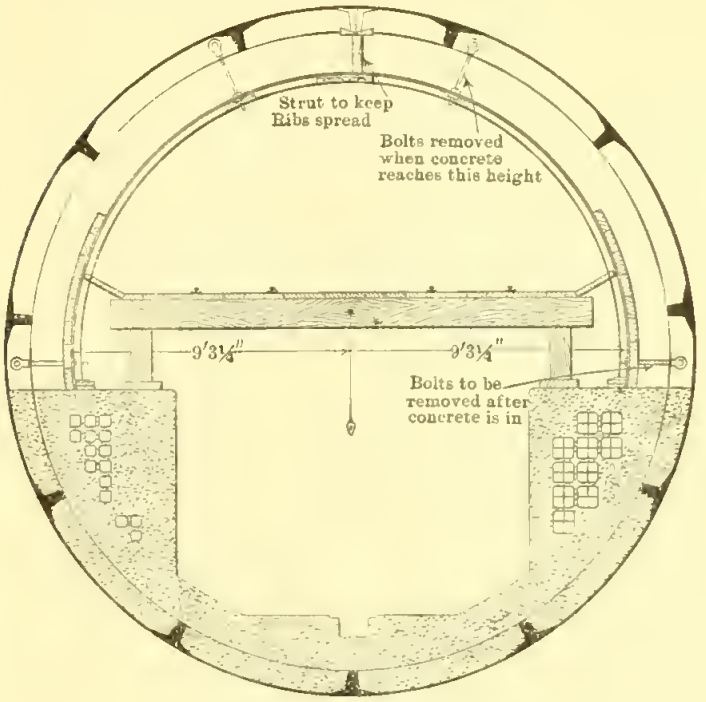
The placing of concrete inside the iron tube was done by an organization entirely separate from the tunneling force. A mixing plant was placed in each of the five shafts. The stone and sand bins discharged directly into mixers below, which, in turn, discharged into steel side-dump concrete cars. All concrete was placed in normal air.

The first step, after the iron lining was scraped clean and washed down and all leaks were stopped, was the placing of biats, marked *B* on Plate LXXIV. These were made up of a 6 by 12-in. yellow pine timber, 17 ft. long, with two short lengths of the same size spliced to its ends by pieces of 12-in. channels, 3 ft. 9 in. long, clamped upon the sides. These biats were placed every 5 ft. along the tunnel in rings having side keys. Next, a floor, 13 ft. wide, was laid on the biats and two tracks, of 30-in. gauge and 6½-ft. centers, were laid upon the floor. There were three stages in the concreting. Fig. 2, Plate LXXIV, shows the concrete in place at the end of the first, and Fig. 3, Plate LXXIV, at the end of the second stage. The complete arch above the bench walls was done in the last operation.

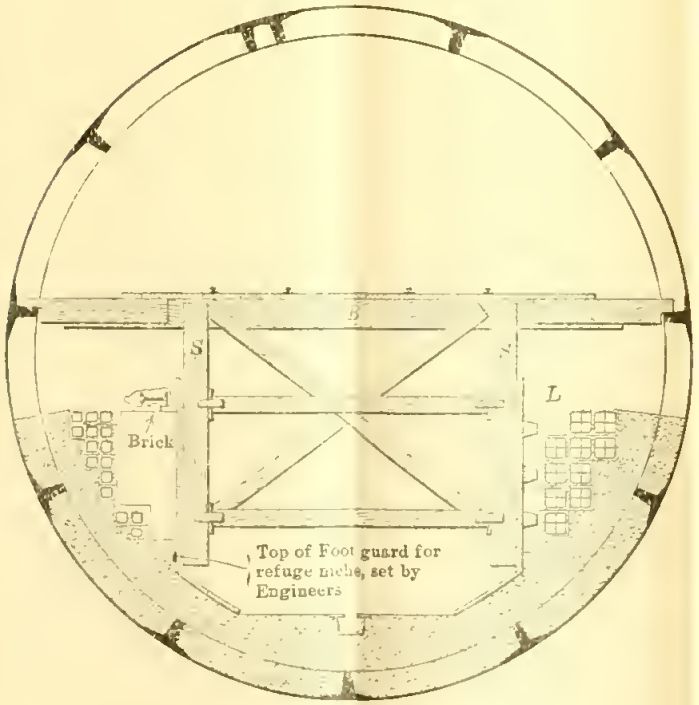
Two 3 by 10-in. soldiers (*SS* in Figs. 1 and 2, Plate LXXIV) were fastened to each biat and braced across by two horizontal and two diagonal braces. To each pair of soldiers a floor template, *T,* was then nailed. The form for the center drain was then suspended as shown in Fig. 1, Plate LXXIV. Three pieces of shuttering, *FFF,* 20 ft. long, were then nailed to the bottom of the soldiers. One is all that would have been needed for the first concrete placed, but it was easier to place them at this stage than later, when there was less room. Three rough shutters were also nailed to the curved portion for the floor template. Opposite each biat, a bracket, *bb,* was then nailed, which carries a set of rough boards which formed the risers for the duct steps. Everything was then ready for concreting except that, where refuge niches occurred, a



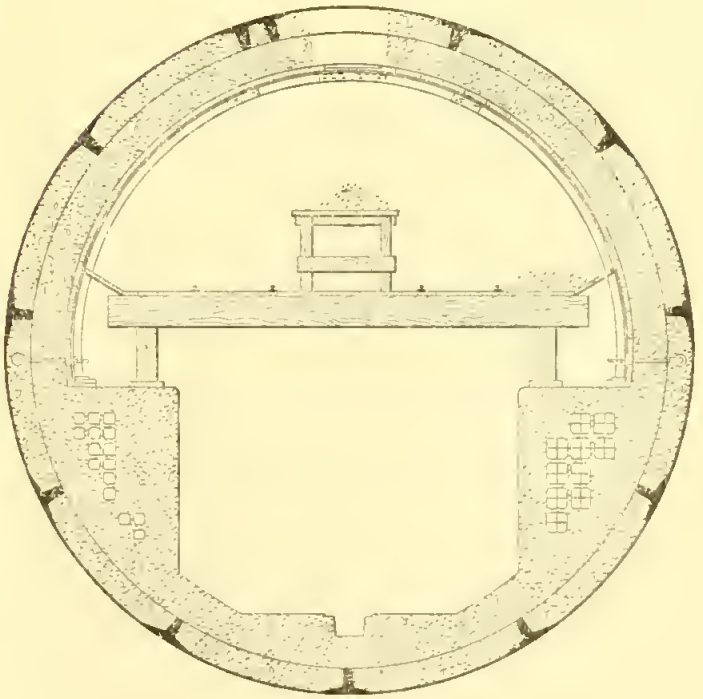
SECTION SHOWING FORMS
FOR INVERT
FIG.1



SECTION SHOWING ARCH FORMS
READY FOR CONCRETE
FIG.3



SECTION SHOWING FORMS
FOR BENCH
FIG.2



SECTION SHOWING FORMS
FOR KEY
FIG.4

form for the portion of the niche below the seat was nailed to the shuttering. This form is shown at *R* in Fig. 1, Plate LXXIV.

The concrete was dumped down on each side from side-dump cars standing on the track, and, falling between the risers for the duct steps, ran or was shoveled under the forms and down into the bottom. The horizontal surface on each side the center drain was smoothed off with a shovel. The workmen became very skillful at this, and got a fairly smooth surface. This concrete was usually placed in lengths of 45 or 60 ft. After setting for about 24 hours, the brackets, *bb*, were removed, together with the shuttering on the steps. The triangular pieces, *t* in Fig. 1, Plate LXXIV, were not removed until later. Instead, a board was laid upon this lower step on which the duct layers could work. This and the triangular piece were not removed until just before the bench concrete was placed. This was important, as otherwise the bond between the old and new concrete would be much impaired by dirt ground into the surface of the old concrete. The ducts were then laid, as shown in Fig. 2, Plate LXXIV.

The remaining shutters for the face of the bench walls were then placed. The remainder of the forms for the refuge niches, *RR*, in Fig. 1, Plate LXXIV, were nailed to the shutters, the steel beam over the niche was laid in place, the forms for the ladders, *L* in Fig. 2, Plate LXXIV, which occur every 25 ft., were tacked to the shutters, the shutters and forms were given a coat of creosote oil, and then all was ready for placing the bench concrete.

The specifications required a 2-in. mortar face to be placed on all exposed surfaces and the remainder to be smoothed with a trowel and straight-edge. After about 48 hours, the biats were blocked up on the bench, and all forms between the bench walls below the working floor were removed.

The centering for the arch concrete consisted of simple 5 by 3½ by $\frac{5}{16}$-in. steel-angle arch ribs, curved to the proper radius, spaced at 5-ft. intervals. Each rib was made up of two pieces spliced together at the top. Two men easily handled one of these pieces. After splicing, the rib was supported by four hanger-bolts fastened to the iron lining as shown in Fig. 3, Plate LXXIV.

In the early part of the work, two additional bolts were used about half way up on the side between the upper and lower hanger-bolts. It was soon found that by placing the strut between the tunnel lining

and the crown of the rib, these hanger-bolts could be dispensed with. The lagging was of 3-in. dressed yellow pine, 12 in. wide, and in 15-ft. lengths. Each piece had three saw cuts on the back, from end to end, allowing it to be bent to the curve of the arch; it was kept curved by an iron strap screwed to the back. The arches were put in, either in 15, 30 or 45-ft. lengths, depending on what was ready for concrete and what could be done in one continuous working. The rule was that when an arch was begun, the work must not stop until it was finished. An arch length always ended in the middle of a ring. The lagging was placed to a height of about 6 ft. above the bench before any concreting was done. When the concrete had been brought up to that point, lagging was added, one piece at a time, just ahead of the concrete, up to the crown, where a space of about 18 in. was left. When the lagging had reached the upper hanger-bolts, they were removed, which left only the two bottom bolts fixed in the concrete. Most of these were unscrewed from the eye and saved, as tin sleeves were placed around them before concreting. Two cast-iron eyes were lost for every 5 ft. of tunnel. To place the key concrete, a stage was set up in the middle of the floor, and, beginning at one end, about 2 ft. of block lagging was placed. Over this, concrete was packed, filling the key as completely as possible. This was done partly by shoveling and using a short rammer, and partly by packing with the hands by the workmen, who wore rubber gloves for the purpose. Another 2 ft. of lagging was then placed, and the operation was repeated, and thus working backward, foot by foot, the key was completed. This is the usual way of keying a concrete arch, but in this case the difficulty was increased by the flanges of the iron lining. It was practically impossible to fill all parts of the pockets formed by these flanges. To meet this difficulty, provision was made for grouting any unfilled space. As the concrete was being put in, tin pipes were placed with their tops nearly touching the iron lining, and their bottoms resting on the lagging. Each pocket was intended to have two of these pipes, one to grout through and the other to act as a vent for the escape of air. Each center key ring had six pipes, and each side key had eight. The bottoms of the pipes were held by a single nail driven half way into the lagging. This served to keep the pipes in position and to locate them after the lagging was taken down.

The cost of labor in the tunnels directly chargeable to concrete was

$1.80 per cu. yd. The top charges, exclusive of the cost of materials (cement, sand, and stone), amounted to $3.92.

Electric Conduits.

In one bench wall of each tunnel there were fifteen openings for power cables and in the other, between the river shafts, there were forty openings for telephone, telegraph, and signal cables. East of the Long Island shaft, the number of the latter was reduced to twenty-four. The telephone ducts were all of the four-way type. The specifications required that the power ducts should have an opening of not less than $3\frac{1}{2}$ in., nor more than $3\frac{7}{8}$ in., and that after laying they should pass a 4-ft. mandrel, $3\frac{3}{8}$ in. at the leading end and $2\frac{3}{8}$ in. at the other. The outside dimension was limited between 5 and $5\frac{3}{8}$ in. The openings of the four-way ducts were required to be not less than $3\frac{3}{8}$ in., nor more than $3\frac{5}{8}$ in., and after laying to pass a 5-ft. mandrel, $3\frac{1}{4}$ in. at the leading end and $2\frac{1}{2}$ in. at the other. The outside dimensions were limited between 9 and $9\frac{1}{2}$ in. All were to be laid in $\frac{1}{4}$-in. beds of mortar. The specifications were not definite as to the shape of the opening, but those used were square with corners rounded to a radius of $\frac{3}{4}$ in. The four-ways were 3 ft. long, and the singles, 18 in.

A study of the foregoing dimensions will show that the working limits were narrow. Such narrow limits would not pay for the ordinary conduit line in a street, where there is more room. In the tunnel greater liberality meant either reducing the number of conduits or encroaching on the strength of the concrete tunnel lining. The small difference of only $\frac{1}{8}$ in. in the size of the mandrel, or a clearance of only $\frac{1}{16}$ in. on each side, no doubt did increase the cost of laying somewhat, though not as much as might at first be supposed. All bottom courses were laid to a string, in practically perfect line and grade, and all joints were tested with mandrels which were in all openings, and pulled forward as each piece of conduit was laid. As the workmen became skillful, the progress was excellent.

All costs of labor in the tunnel chargeable to duct laying amounted to $0.039 per ft. of duct; top charges brought this up to $0.083.

The serious problem was to guard against grout and mortar running into the duct opening through the joints from the concrete, which was a rather wet mixture. Each joint was wrapped, when laid, with canvas, weighing 10 oz. per sq. yd., dipped in cement grout immediately before

using. These wraps were 6 in. wide, and were cut long enough to go around the lap about the middle of the duct. As soon as all the ducts were laid, the entire bank was plastered over with fairly stiff mortar, which, when properly done, closed all openings. The plastering was not required by the specifications, but was found by the contractor to result in a saving in ultimate cost.

The concrete on the two sides of the bank of ducts was bonded together by 2 by $\frac{1}{8}$-in. steel bonds between the ducts, laid across in horizontal joints. Both ends were split into two pieces, 1 in. long, one of which was turned up and the other down. These bonds projected $1\frac{1}{2}$ in. into the concrete on either side. Where the bond came opposite the risers of the duct step, against which the ducts were laid, recesses were provided for the projecting bond. This was done by nailing to the rough shutters for the steps a form which when removed left a dove-tailed vertical groove. This form was made in two pieces, one tapering inward and the other with more taper outward. As the bonds were placed, these grooves were filled with mortar.

The ducts usually received their final rodding with the specification mandrel a month or more after they were laid, after which all openings into splicing chambers were stopped by wooden plugs, 8 in. long tapering from $3\frac{3}{4}$ in. at one end to $2\frac{3}{4}$ in. at the other end, and shaped to fit the opening tightly. At first the plugs were paraffined, to keep them from swelling and breaking the ducts, but were not successful, as the paraffin lubricated them so that they would not stay in place. They were expensive, and there was some swelling in the best that were obtained. A better plug was made by using no paraffin, but by making six saw cuts, three horizontal and three vertical, in the larger end, cutting to within about 2 in. of the smaller end. The swelling of the wood was then taken up by the saw cuts and the spring of the wood.

The splicing chambers are at 400-ft. intervals. They are 6 ft. long, 4 ft. 9 in. high, with a width varying from 3 ft. 2 in. at the top to 1 ft. 2 in. at the bottom.

MEMOIRS OF DECEASED MEMBERS.

JOHN FISKE BARNARD, M. Am. Soc. C. E.*

DIED FEBRUARY 6TH, 1910.

John Fiske Barnard was born in Worcester, Mass., on April 23d, 1829. He was graduated from the Bridgewater Normal School, and from Rensselaer Polytechnic Institute.

In November, 1850, Mr. Barnard entered the railway service. He held various engineering and operating positions with the Grand Trunk Railway and its subsidiary lines in Lower Canada, and served as Chief Engineer of the Grand Trunk South of the St. Lawrence River for the last three years of his connection with that road.

In May, 1869, he went to the Missouri Valley Railroad as Superintendent and Chief Engineer. During the same year he was appointed Chief Engineer of the Kansas City-St. Joseph and Council Bluffs Railroad, and remained with this road and the Hannibal and St. Joseph Railroad (both now a part of the Burlington Missouri Lines), as Chief Engineer, General Superintendent, and General Manager, until 1886. During this time Mr. Barnard was also President of the Atchison Union Depot Company and the St. Joseph Union Stock Yards Company, Secretary and Treasurer of the St. Joseph Depot Company, and Director in various railroad companies.

In 1886, Mr. Barnard was appointed President and General Manager of the Ohio and Mississippi Railway, which position he occupied until 1892. From that time until 1893, he was engaged on several reports of projected railroads and appraisals of industrial and railroad properties.

From 1893 to 1898, Mr. Barnard was Receiver of the Omaha and St. Louis (now Wabash) Railway, during part of which time he was also President of the Alton Bridge Company, and Receiver of the St. Clair-Madison and St. Louis Belt Line.

In the spring of 1905 he moved to Los Angeles, Cal., where he lived until February 6th, 1910, when, after an illness of several months, he died at his home at the age of 81 years.

Mr. Barnard was elected a Member of the American Society of Civil Engineers on September 1st, 1880. He was also a Member of the American Geographical Society.

* Memoir prepared by W. K. Barnard, Assoc. M. Am. Soc. C. E.

ROBERT L. ENGLE, M. Am. Soc. C. E.*

DIED OCTOBER 16TH, 1909.

Robert L. Engle was born on December 5th, 1846. He was a product of the time when opportunities for technical training were few, so that his engineering education was gained largely by contact with actual work. He began his professional career after the Civil War, in which he served for two years in the One Hundred and Forty-eighth Indiana Volunteer Infantry.

The first construction work of any note on which Mr. Engle was engaged was the building of the Ohio and Mississippi Railroad, now a part of the Baltimore and Ohio System, extending from Cincinnati to St. Louis. Later, and up to 1878, he was connected with the construction of the Cincinnati Southern Railway, Cincinnati's municipally owned railway, as Division Engineer, at Ray Springs, Tenn. This work included several tunnels and other heavy work in the mountain territory.

After the completion of the Cincinnati Southern, Mr. Engle went West, and was engaged in the construction of the Santa Fé Railroad at Trinidad, Colo., in the capacity of Assistant Chief Engineer. Under his direction the Royal Gorge Hanging Bridge was built, and much other interesting work was carried out. Mr. Engle's forte was location, and in the mountainous regions of the West he found ample exercise for this faculty. From Trinidad he moved to Santa Fé, N. Mex. His name is borne by Engle, N. Mex., now a thriving Western town.

While still in the West, Mr. Engle was connected with the Mexican Central Railroad, at Chihuahua, Mexico, on construction work, and with the Denver and Rio Grande Railroad. It is thus seen that he played a part in much of the important pioneer railroad development of the mountain region of the West.

In 1885, Mr. Engle began work on the location and construction of the Chicago, Burlington, and Northern Railroad, now part of the Burlington System, being located at St. Paul, Minn., as Assistant Chief Engineer of that portion of the line north of La Crosse, Wis. Later, his jurisdiction included the whole line. During 1887 and a part of 1888, he had charge of the construction of the Illinois Valley and Northern Railroad, as Chief Engineer, at La Salle, Ill. In the latter part of 1888 he conducted surveys for coal branch lines connecting with the Chesapeake and Ohio Railway, in the mountains of West Virginia.

Beginning in September, 1889, Mr. Engle was Resident Engineer on the construction of the Louisville and Jeffersonville Bridge over the

* Memoir prepared by O. E. Selby, Jun. Am. Soc. C. E.

Ohio River. During his term of service the substructure, involving several deep pneumatic foundations, was built, and parts of the approaches were erected. During his stay at Louisville Mr. Engle was selected as Arbitrator in a matter of disputed classification between the company and the contractor for the Pike's Peak Rack Railroad, and effected a satisfactory settlement. Among other things his later service included location work on the Tennessee Central Railroad, in 1892; location and construction work for the Missouri, Kansas and Texas Railroad, in Arkansas; and construction work on the Tidewater Railroad, now the Virginian Railway, at Princeton, W. Va. At the time of his death he was employed as Engineer for the contracting firm of Carpenter and Boxley, at Johnson City, Tenn.

With the death of Robert L. Engle, the Profession loses one of those sturdy, self-made engineers, to whom the country is largely indebted for pushing railroad construction overland and through the West. In character, rugged like the mountains with which he was associated, he was still the gentlest of souls to those associated with him in subordinate capacities. The writer knew him as Chief and friend for many years, and cannot recall any departures from the lines of the highest dignity, rectitude, good habits, and good nature.

Mr. Engle was a Member of the Engineers' Club of Cincinnati from the time of its organization. He maintained his home in Cincinnati for twenty-one years, while his engagements kept him at various other places.

On February 20th, 1879, Mr. Engle married Miss Sallie McQueety, of Cincinnati, and is survived by her and their son and two daughters. His family and social relations were most happy, although his enforced absences from home kept him from much of the social contact which his qualities deserved.

Mr. Engle was elected a Member of the American Society of Civil Engineers on September 7th, 1881.

CHARLES HERBERT DEANS, Assoc. M. Am. Soc. C. E.*

DIED MARCH 7TH, 1909.

Charles Herbert Deans was born in Chester, Delaware County, Pa., on November 30th, 1863, and died at his home in Phœnixville, Pa., on March 7th, 1909.

His father, Charles Woodbury Deans, was prominent in educational work, and was active in the early organization and in the popularization of the Common School System of the State of Pennsylvania.

On his father's side Mr. Deans was descended from the Deans and Sterling families, who, immediately following the War of the Revolution, emigrated from Connecticut to Susquehanna and Wyoming Counties, Pennsylvania. His mother was Priscilla Lyons Williams, of Chester, Delaware County, Pa., who was descended from the Lyons family of New Jersey and the Williams and Pennell families of Pennsylvania.

From both his father and his mother Mr. Deans inherited a taste and aptitude for study. His youthful environment was among books and in an atmosphere which naturally encouraged the desire he early formed to fit himself for a professional life.

His education was begun in private schools, but later he attended the public schools, and was graduated from the High School at Phœnixville, Pa., in 1881. He spent the next four years in practical work, learning business methods, becoming an excellent and accurate accountant, and familiarizing himself, in the works of the Phœnix Iron Company, with mill and shop methods and practice, and the metallurgy of iron and steel.

In 1885, Mr. Deans entered Lehigh University, well prepared in his studies, with a mind ripe for the absorption of further knowledge, and a temperament for enjoying to the utmost the four years of University life before him. He was a good student, standing well up in the first quarter of his class. He was elected a member of Theta Delta Chi Fraternity, was one of the Editors and Assistant Business Manager of the college Annual in his Junior year, and Business Manager of the Engineering Journal in his Senior year. He was graduated in 1889 with the degree of C. E.

As a boy Mr. Deans was fond of games and all healthy outdoor sports. He was a lover of Nature and of animals, fond of fishing and hunting, and was never happier than when roaming the beautiful woods and mountains of his native State. With such tastes it was natural to find him, in his college days, a participator in, and an enthusiastic supporter of, athletic games.

* Memoir prepared by Emil Diebitsch and Edwin S. Jarrett, Members, Am. Soc. C. E.

Not only in athletics, but in all things pertaining to Lehigh University, Mr. Deans was a most loyal and enthusiastic son of his Alma Mater, both at college and after he had gone out into the world. He thoroughly appreciated the benefits derived from his technical training, and was so eager that others should share them, that early in his business career he advanced sufficient funds to two ambitious young men to carry them through Lehigh.

Immediately after graduation Mr. Deans entered the employ of Sooysmith and Company, the well-known foundation engineers and contractors. He rapidly advanced to positions of responsibility with this company, and, in 1895, became its Vice-President and Chief Executive Officer. When, a year or two later, Charles Sooysmith, M. Am. Soc. C. E., retired from active business, Mr. Deans organized, from the Sooysmith and Company staff, the Engineering Contract Company, of which he became President. Pressure of business seriously undermining his health, he was forced to give up temporarily all work in 1900, and to spend the next two years in the mountains of Northern Pennsylvania. On regaining his health, he associated himself with the firm of John Monks and Son, of New York City, and, at the time of his death, he was Second Vice-President of that company.

While under his executive charge, both Sooysmith and Company and the Engineering Contract Company, constructed a number of the most important bridge foundations in the United States, and the former firm first successfully introduced pneumatic work in the foundations of the modern high office buildings of New York City, notably the Manhattan Life, Washington Life, Standard Oil, and Empire Buildings on Lower Broadway. At the time of his death, Mr. Deans was in full charge of the building of the piers of the reconstructed Baltimore and Ohio bridge over the Susquehanna River, at Havre de Grace, Md.

In the early years of his connection with Sooysmith and Company, Mr. Deans was employed on work in the field, rising from subordinate positions to that of Superintendent in responsible charge of work. During this period he acquired an intimate and practical knowledge of foundation construction, and his subsequent career gave evidence of the value of this training. Being thus well-equipped, Mr. Deans soon became notable as a business engineer. His judgment on all substructure engineering problems was quick and keen, his thorough technical knowledge being supplemented by his penetrating practical sense. His business ability was of a high order, and his efficiency was largely increased by his industry and methodical habits. As a negotiator, he was in the first rank. His quick appreciation of the essentials in business transactions, his fertile resource in the most complicated financial dealings, his patience and persistence in the face of discouragement or delay, and his inflexible determination when once his

decisions were reached, were qualities which placed him in the highest rank as a contracting engineer. To those with whom he came in close contact, Mr. Deans will always be remembered as exemplifying the ideal combination of technical training with business efficiency.

He lightened the seriousness of his business transactions with a quick sense of fun, a fondness for a good story, and an infectious good humor. His genuine interest in the work of his associates and his unfeigned delight in their success won him many friendships which lasted throughout his life and which now keep his memory warm in the hearts of those who were fortunate enough to know him intimately. Strong of will, keen and clear-sighted in business transactions, loyal to his friends and to the interests entrusted to him, he was, above all, a genial, honorable, many-sided man, who loved his fellow men.

Mr. Deans leaves a mother, Mrs. Charles W. Deans, of Phœnixville, Pa., a brother, John Sterling Deans, M. Am. Soc. C. E., Chief Engineer of the Phœnix Bridge Company, and two sisters, Mrs. R. Barclay Calley, of Seattle, Wash., and Mrs. Elmer E. Keiser, of Tacony, Pa.

In 1893, Mr. Deans married Miss Helen Arnold of West Chester, Pa., who, with two sons, Charles Woodbury, aged 15, and Malcolm Arnold, aged 13, survives him.

Mr. Deans was elected a Junior of the American Society of Civil Engineers, on December 3d, 1890, and an Associate Member on May 6th, 1896.

WILLIAM MEIER, Assoc. M. Am. Soc. C. E.*

DIED FEBRUARY 14TH, 1910.

William Meier, the son of the Reverend Jacob L. and Mary Meier, was born in Muscatine, Iowa, on April 10th, 1878, the family moving to Chicago, Ill., in the same year.

Mr. Meier received his education in the public schools of Chicago and at the University of Illinois, from which he was graduated in 1901, with the degree of B. S. in Civil Engineering.

After his graduation, Mr. Meier was engaged with various firms, principally in bridge and structural work. For a time he was with William M. Hughes, M. Am. Soc. C. E., and in January, 1905, he entered the service of the Scherzer Rolling Lift Bridge Company, as Assistant in the Chicago office; and later was appointed Assistant Engineer and Eastern Representative, with headquarters in New York City. At the time of his death, Mr. Meier was employed in the Bridge Department of the Chicago and North Western Railway.

On February 14th, 1910, in diving from a spring-board, in the natatorium of the Young Men's Christian Association, he struck his head against the side or bottom of the tank. When his body was taken from the water, life was extinct, and all efforts at resuscitation were futile.

Mr. Meier took great interest in all that pertained to his profession.

He was elected an Associate Member of the American Society of Civil Engineers, on June 1st, 1909. He was also a Member of the Western Society of Engineers.

* Memoir prepared by William A. Theodorsen and E. James Fucik, Associate Members, Am. Soc. C. E.

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